FOUR WATERFLOODING PROJECTS IN GREENWOOD COUNTY, KANS., 1960

By Kenneth H. Johnston

information circular 7969

UNITED STATES DEPARTMENT OF THE INTERIOR
Fred A. Seaton, Secretary

BUREAU OF MINES
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Johnston, Kenneth Howard

Four waterflooding projects in Greenwood County, Kans., 1960. [Washington] U.S. Dept. of the Interior, Bureau of Mines [1960]

ii, 36 p. illus., maps, tables. 26 cm. (U.S. Bureau of Mines. Information circular 7969)

1. Oil field flooding - Kansas - Greenwood Co. I. Title (Series)

TN23.U71 no. 7969 622.06173

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FOUR WATERFLOODING PROJECTS IN GREENWOOD COUNTY, KANS., 1960[1]

by

Kenneth H. Johnston[2]

INTRODUCTION AND SUMMARY

For the past several years, Bureau of Mines petroleum engineers have arranged tours of selected waterflooding projects for the spring meetings of the Kansas-Oklahoma Waterflood Association. These tours are conducted to demonstrate unique operating methods and new field equipment and to provide additional opportunities for exchanging information. Each of these tours has been supplemented by a published report describing in detail the projects visited. This report has been prepared for distribution during the 1960 spring tour of four waterflooding projects in Greenwood County, Kans. (fig. 1).

Three of the projects produce oil from the Bartlesville sand, and one produces from the Cattleman sand. The Bartlesville-sand floods have been in operation from 4 to 12 years and have produced about 3,910,000 barrels of waterflood oil from the injection of approximately 64,715,000 barrels of water, a cumulative water-injected to oil-produced ratio of 17 to 1. The Cattleman-sand flood, which has been operating for 3-1/2 years, has produced about 842,000 barrels of waterflood oil from the injection of approximately 9,305,000 barrels of water, a cumulative water-injected to oil-produced ratio of 11 to 1.

Although increases in oil production were observed for many years near plugged and abandoned wells, the Kansas Corporation Commission did not authorize waterflooding until 1935. The first legal flood in the State, the York State De Malorie "C" in Greenwood County,[3] began that year. Waterflooding on some earlier projects in Greenwood County was described in Bureau of Mines publications.[4,5]

1/ Work on manuscript completed February 1960.
2/ Petroleum engineer, Bureau of Mines, Region IV, Bartlesville, Okla.
3/ Taliaferro, D. B. and Eakin, J. L., Burkett Unit and York De Malorie C (Kans.): Oil and Gas Compact Bull., vol. 14, June 1955, pp. 110-114.
4/ Grandone, Peter, History of Water-Flooding of Oil Sands in Kansas: Bureau of Mines Rept. of Investigations 3761, 1944, 146 pp.
5/ Powell, J. P., Water Flooding of Oil Sands in Butler and Greenwood Counties, Kans.: Bureau of Mines Inf. Circ. 7750, May 1956, 42 pp.

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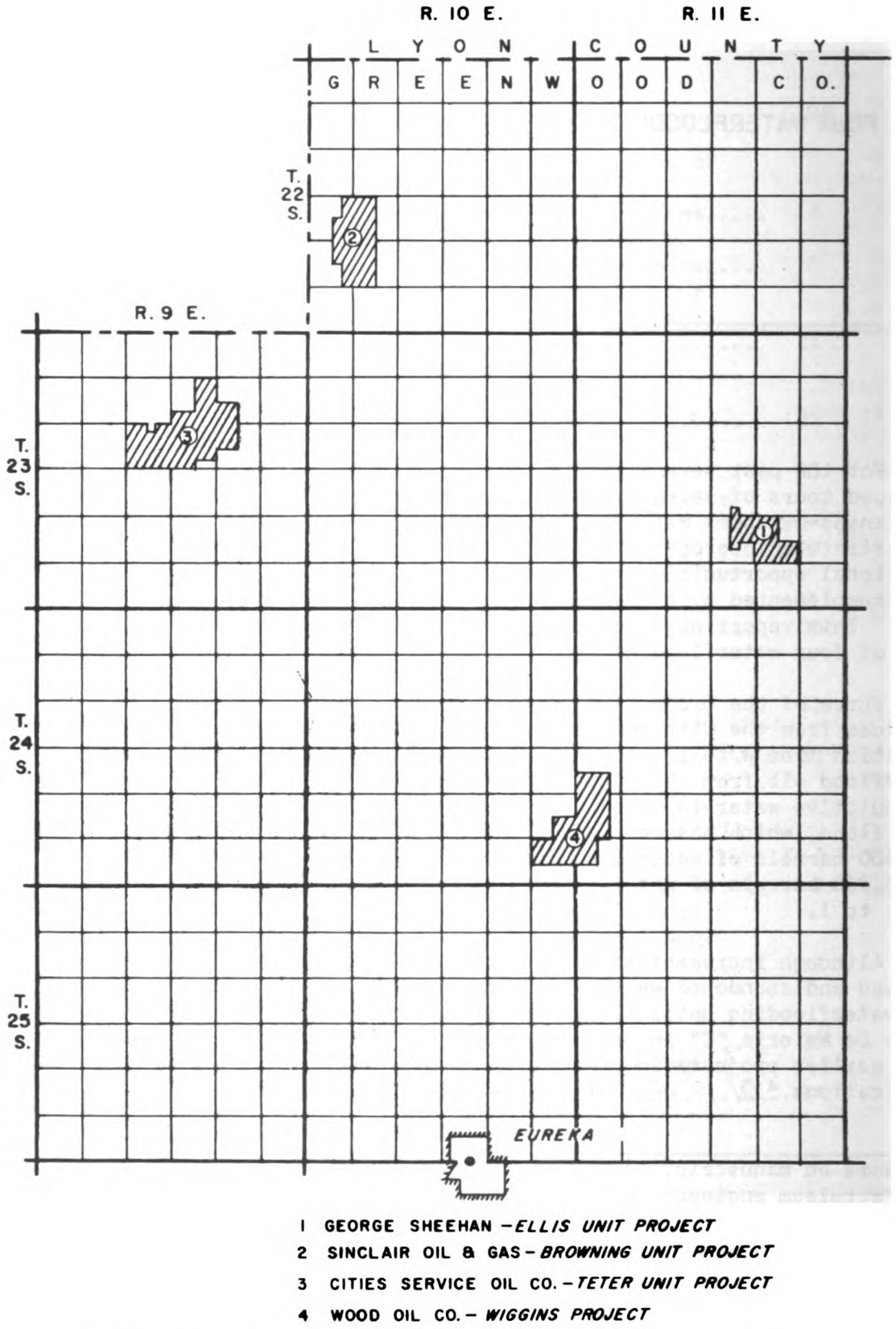

FIGURE 1. · Map Showing Location of Four Waterflooding Projects in Greenwood County, Kans., Jan. 1, 1960.

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Two projects covered in this report use Arbuckle water for injection, and two use water from the Douglas sand. Three projects take advantage of surface elevation and height of separator tanks to collect by gravity flow the produced brine at the respective watertreating plants. On one project, separate injection systems distribute the produced and Arbuckle brines. The produced-brine system serves input wells north of the plant, and the Arbuckle system serves wells south and west of the plant. On this project the produced brine is collected and treated in the bottom two rings of a 55,000-barrel tank that has been partitioned into three sections to receive raw water, clear water, and backwash water.

Another project uses a simplified treating plant consisting of four high 500-barrel receiving tanks and two injection pumps. Produced brine and Douglas supply water flow by gravity in closed systems to the receiving tanks. From the receiving tanks, the water flows by gravity to the suctions of the injection pumps.

Information on each individual project covered in this report includes the early history, methods used to complete wells, source and treatment of the water used for flooding, oil production-decline curves, mineral analyses of waters, typical electric logs and core analyses, and the results of waterflooding.

ACKNOWLEDGMENTS

This report on four waterflooding projects in Greenwood County, Kans., was prepared by the Bureau of Mines, U. S. Department of the Interior, under a cooperative agreement with the Kansas State Board of Health.

The writer gratefully acknowledges the cooperation of the officials and employees of the oil companies and the individuals operating the described waterflooding projects, who made this report possible by furnishing engineering and statistical data on their respective projects.

REPORT ON FOUR INDIVIDUAL PROJECTS

George Sheehan Ellis Unit Project

The George Sheehan Ellis unit in parts of secs. 22, 26, and 27, T. 23 S., R. 11 E., covers 375 productive acres of which 140 acres had been developed by December 1959 (fig. 2).

By August 1955, a flood operated by Phillips Petroleum Co., south of the Ellis Unit, had been extended to the south line of the property, and Sheehan started a pilot flood by converting an oil well in the SW¼SE¼SW¼ of sec. 26 to an input well. Arbuckle water for injection was furnished from the adjoining flood. In August 1958, an agreement was made with the offset operator to drill alternate input wells along the west line of the NE¼ of section 27. By June 1959 Sheehan had completed two Douglas water-supply wells and a pressure plant. The flood was extended to include most of the NE¼ of sec. 27.

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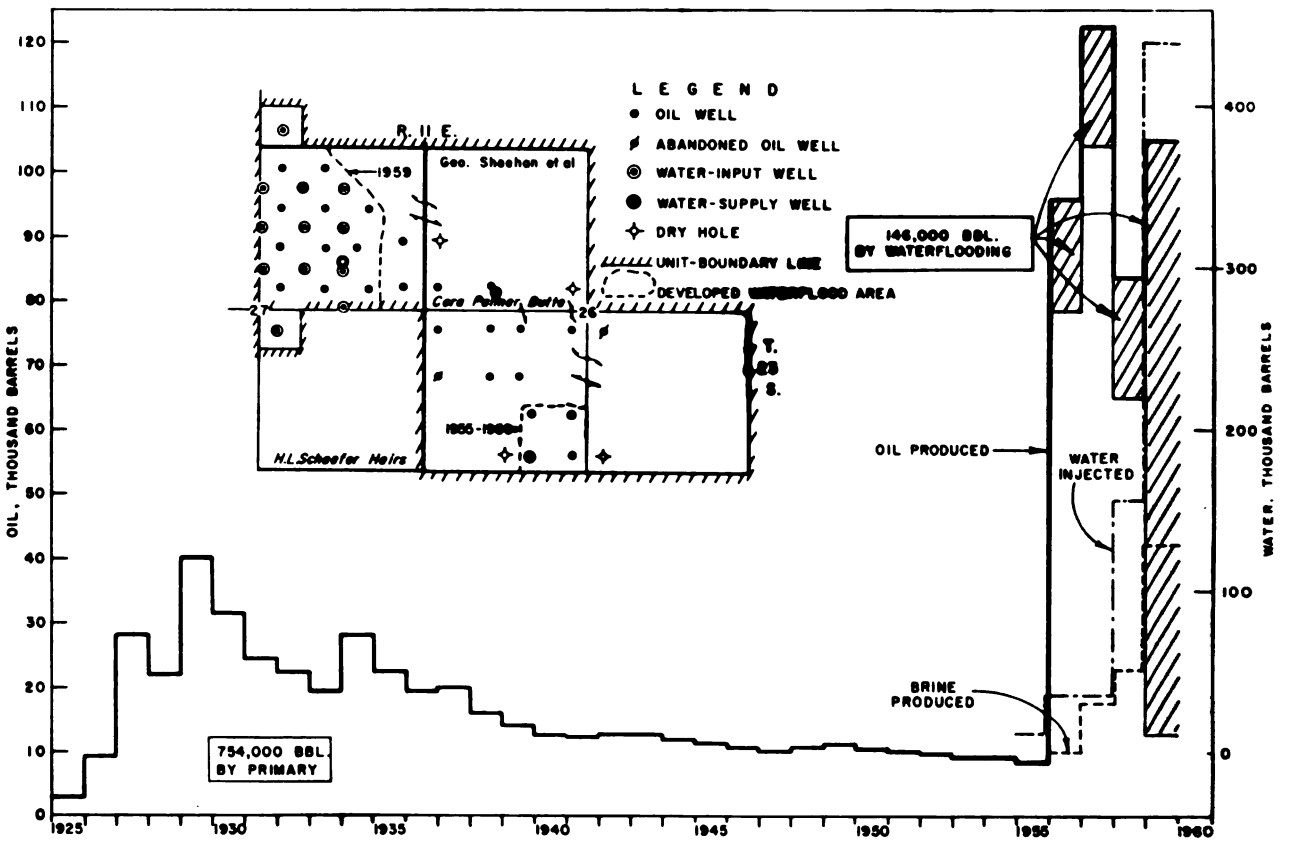

FIGURE 2. - Map and History of Production of George Sheehan Ellis Unit Project, Greenwood County, Kans., Jan. 1, 1960.

The formation flooded is the Bartlesville sand which, in this area, is found at an average depth of 1,940 feet and has an average effective thickness of 17 feet. The unit is in a trend of shoestring development that links the Edward extension of the Seely pool to the northwest with the Hamilton pool to the southeast. The sand in the southeast part of the unit is brownish and locally known as "Brothers" sand. The remaining productive Bartlesville sand in the unit is white and is locally called either the "Beal" or the "Ellis" sand. Although there may be a gradation in depositional characteristics, petroleum engineers believe that the two sands are continuous. Analyses of a core taken before waterflooding indicate that the Bartlesville sand in the unit has an average porosity of 17.5 percent, an average permeability to air of 7.6 millidarcys, an average oil saturation of 18 percent, and an average water saturation of 46 percent. Figure 3 shows the result of an analysis of a representative core taken in 1957.

History Before Flooding

The first well on leases now in the Ellis unit was completed in January 1925 in the NW¼SE¼ of sec. 26, T. 23 S., R. 11 E. Development was continued

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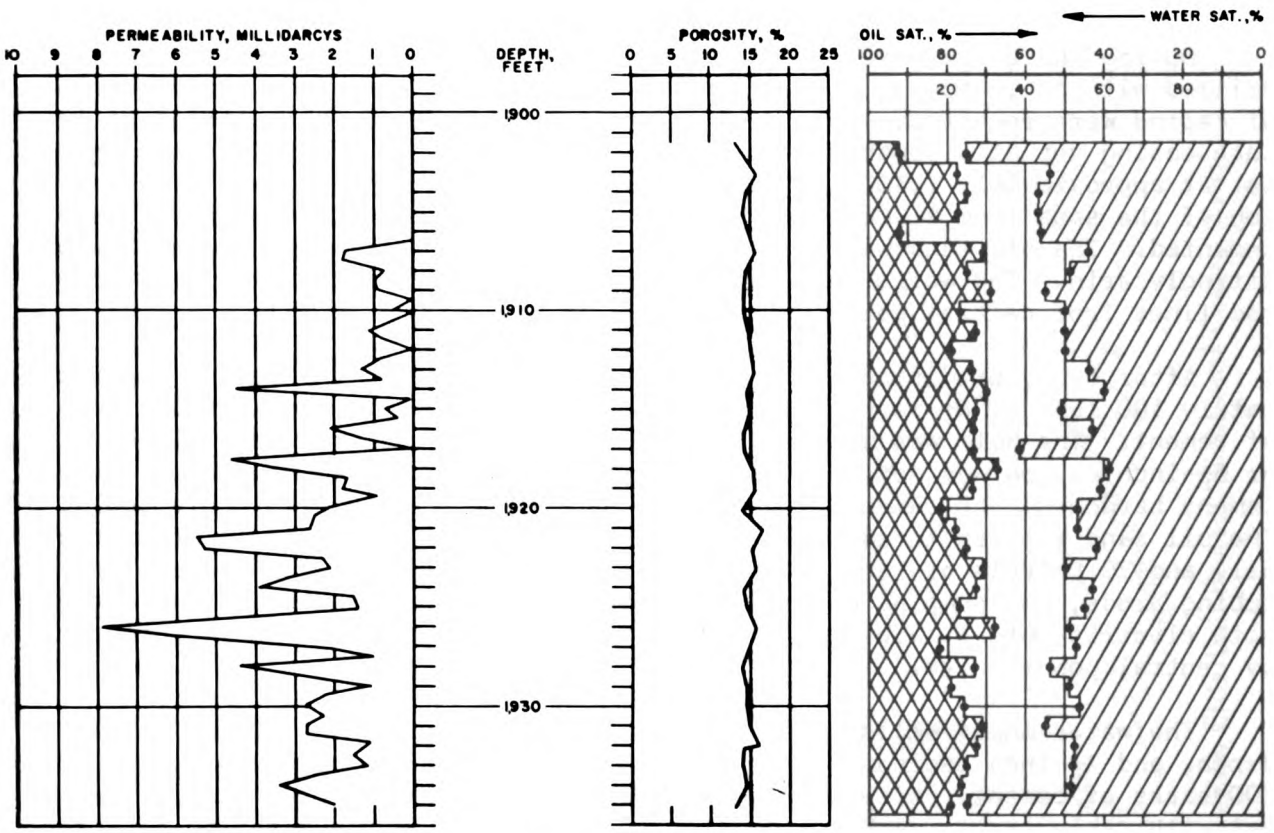

FIGURE 3. - Representative Core Analysis of Bartlesville Sand, George Sheehan Ellis Unit Project, Greenwood County, Kans.

intermittently during the succeeding years. By 1937, 13 oil wells and three dry holes had been drilled in the W½ of sec. 26. The initial daily production of these wells ranged from 15 to 125 barrels of oil and averaged approximately 50 barrels. Except for an oil well drilled in 1941, no additional acreage was developed on the Ellis unit until 1956, when several wells were drilled in the NE¼ of sec. 27. Primary development of this part of the unit was rapid. By February 1958, most of the wells in the NE¼ of sec. 27 had been drilled. The initial daily rate of oil production from these wells ranged from 10 to 50 barrels and averaged approximately 25 barrels.

The composite production history of the Ellis unit, showing the normal rate of decline during primary operation and the status of the wells on January 1, 1960, is shown in figure 2. Development of the W½ of sec. 26 resulted in a peak annual rate in oil production of approximately 40,000 barrels in 1929. From this peak, the annual rate of production declined gradually, except for a peak of 28,000 barrels resulting from additional drilling in 1934 to a low of approximately 8,000 barrels of oil in 1955. Primary development of the NE¼ of sec. 27 in 1956 led to a new annual peak of 122,000 barrels of oil in 1957. From 1925 to 1929 an estimated 753,000 barrels of oil was recovered by primary methods.

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Method of Completing and Operating Wells

During the early development of leases in the Ellis unit, wells were drilled with cable tools. Because of the number of water sands, three strings of casing were required. Most of the wells were started with a string of 12½-inch casing set at a depth of 400 to 500 feet. A string of 8¼-inch casing was set at approximately 1,400 feet and a string of 6¼-inch casing was set at the top of the sand from 1,900 to 1,950 feet. None of the strings of casing was cemented. The oil sand was drilled and shot with approximately 120 quarts of nitroglycerin. The wells were pumped by individual pumping jacks actuated by rod lines from central power units.

After 1955, producing wells were drilled with rotary equipment. Approximately 100 feet of 8¼-inch surface casing was set and cemented with 30 sacks of cement. The hole was drilled to the top of the oil sand, where either 4½- or 5½-inch casing was set and cemented with 100 sacks of cement. After the cement hardened, the cement plug and oil sand were drilled with cable tools. The oil sand was fractured with 10,000 pounds of sand, 100 barrels of viscous oil, and 70 barrels of lease oil. The wells were equipped with conventional tubing, rods, and pumping units. The pumping units were individually powered with electric motors. Several of the older wells in the flood area were pumped by central power units.

The water-input wells were drilled with rotary equipment to the total depth, and 4½-inch casing was set and cemented at the top of the oil sand with 300 sacks of cement. After the cement had set, the cement plug was drilled out with cable tools. A Baker tripler cementing shoe was run during cementing to protect the pay sand from cement filtrate.

Source and Treatment of Water

Before June 1959, when two Douglas-sand water supply wells were drilled and a water-treating plant was constructed on the Ellis unit, Arbuckle water for injection was purchased from the Phillips Petroleum Co. This firm was operating waterfloods to the south and west of the unit. Figure 4 shows the water-treating plant constructed on the Ellis unit. Water from the Douglas supply wells is pumped by a conventional pumping unit into an aerator tank equipped with spray nozzles. Return water from the gun barrel at the tank battery is pumped to the aerator tank and is mixed with the Douglas water. The aerated water flows to the treating house where, for each 1,500 barrels of water, 50 pounds of lime is added to adjust pH. Two ounces of potassium permangate also is added as an oxidant. The treated water flows through a cement flume into the settling pond. The pond, divided by a wooden baffle, allows the products from aeration and chemical reactions to settle out of the water. A centrifugal filter-charging pump forces the treated water from settling pond through two closed rapid filters and into a 7-inch header line. This is a common line between the clear-water tank and the suction of the high-pressure injection pump. The filters are backwashed approximately once a day or when necessary.

Operation of the water plant is automatically controlled by three liquid-level controls. Two upper switches control the operation of the filter-charging

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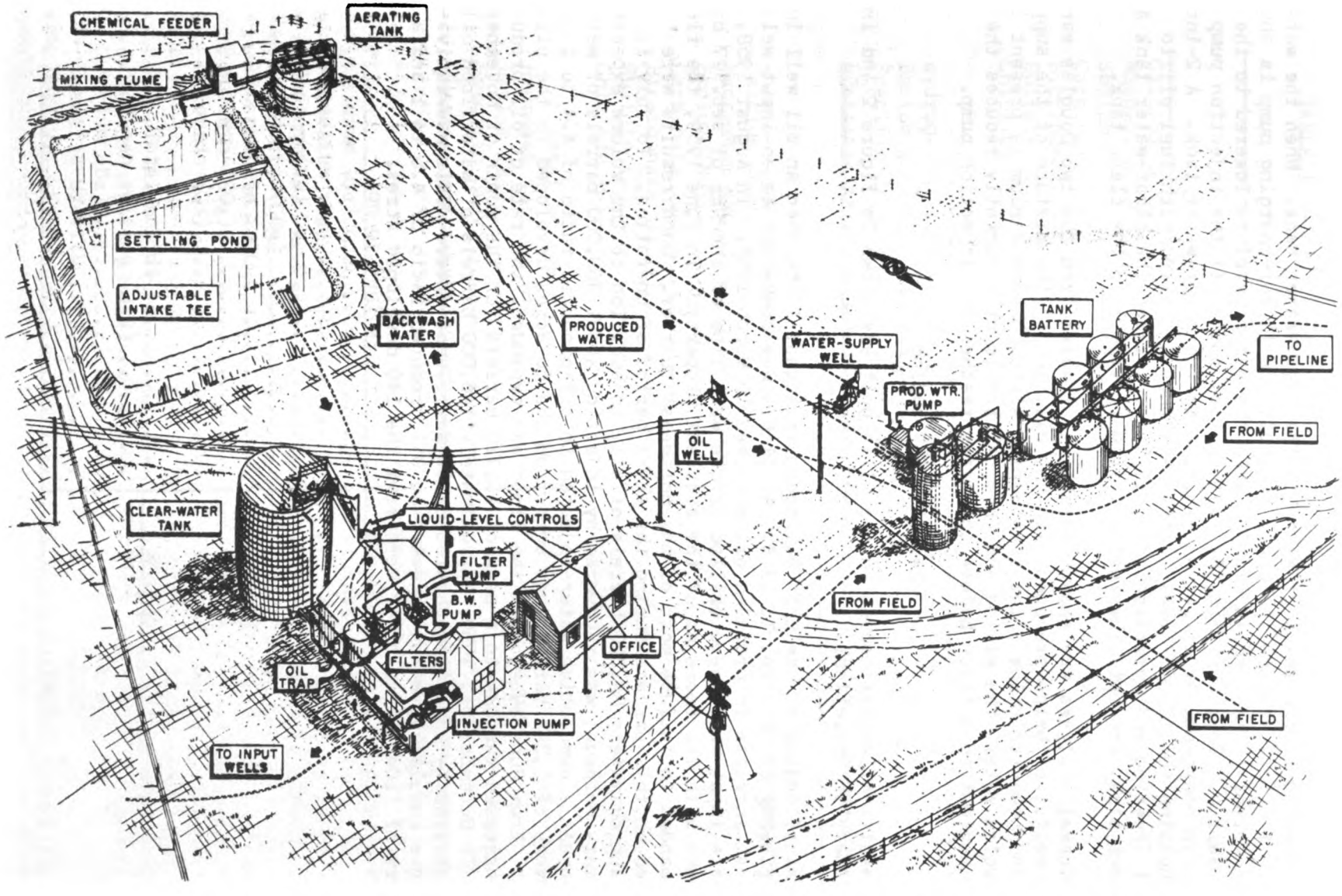

FIGURE 4. - Water-Treating Plant of George Sheehan Ellis Unit Project, Greenwood County, Kans.

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pump according to the level of water in the clear-water tank. When the water level in the tank reaches the upper control, the filter-charging pump is shut off; conversely, the pump is started when the water level is lowered to the middle switch. The lower liquid-level control shuts off the injection pump in case of an emergency or of low-water level in the clear-water tank. A 2-inch riser holding the liquid-level control switches is filled with fuel oil to prevent freezing and corrosion. An oil trap, between the clear-water tank and the riser pipe, prevents the fuel oil from flowing into the clear tank.

Mineral analyses are shown in table 1 of water from the two Douglas sand supply wells, of brine produced with the oil, and of the mixture of the supply water and produced brine after treatment. Although some barium is present in the Douglas water, the mixing and chemical treatment apparently reduces the barium content to a trace before the water reaches the injection pump.

Results of Flooding

Results of waterflooding on the Ellis unit are shown in figure 2 and in the Summary of Operations.

Waterflooding on the unit was begun in August 1955, when an oil well in the SW¼SE¼SW¼ of sec. 26, T. 23 S., R. 11 E., was converted to an input well. The first increase in produced oil occurred in March 1956. In August 1958, alternate input wells were drilled on the west line of the NE¼ of sec. 27 by agreement with the operator of the adjacent property. In June 1959, the flood was expanded to include most of the northeast quarter. Good results were achieved on this project during the short period of operation. To July 1, 1959, approximately 84,000 barrels of oil, in addition to the volume expected by primary methods, was recovered by injecting about 368,000 barrels of water. This equals a cumulative water-injected to oil-produced ratio of 4.4 to 1 and a recovery of 1,397 barrels per acre from the 60 acres developed in the pilot floods. From June 1959, when the flood was expanded, the rate of oil production increased rapidly to a peak of 10,710 barrels for the month of November 1959. To December 31, 1959, approximately 146,000 barrels of waterflood oil was recovered by injecting about 680,000 barrels of water. This was equivalent to a cumulative water-injected to oil produced ratio of 4.6 to 1 and a recovery of 1,041 barrels per acre from the 140 developed acres.

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TABLE 1. - Mineral analyses of injection waters, Geo. Sheehan, Ellis unit project, Greenwood County, Kans.

Ion or Radical	Douglas sand water: Milligrams per liter	Douglas sand water: Reacting values, percent Palmer
Calcium (Ca)	4,580	7.09
Magnesium (Mg)	750	1.91
Sodium (Na)	30,400	41.00
Carbonate (CO_3)	0	0
Bicarbonate (HCO_3)	120	.06
Sulfate (SO_4)	393	.25
Chloride (Cl)	56,800	49.69
Total solids	93,043	100.00
Hydrogen sulfide (H_2S)	-	
Barium (Ba)	55	
Specific Gravity	1.065	
pH	7.58	

Ion or Radical	Produced brine: Milligrams per liter	Produced brine: Reacting values, percent Palmer
Calcium (Ca)	4,700	6.96
Magnesium (Mg)	760	2.07
Sodium (Na)	28,400	40.97
Carbonate (CO_3)	0	0
Bicarbonate (HCO_3)	77	.05
Sulfate (SO_4)	760	.52
Chloride (Cl)	52,800	49.43
Total solids	87,497	100.00
Hydrogen sulfide (H_2S)	-	
Barium (Ba)	Trace	
Specific Gravity	1.061	
pH	7.51	

Ion or Radical	Treated mixed water: Milligrams per liter	Treated mixed water: Reacting values, percent Palmer
Calcium (Ca)	4,660	7.56
Magnesium (Mg)	780	2.08
Sodium (Na)	28,600	40.36
Carbonate (CO_3)	0	0
Bicarbonate (HCO_3)	70	.04
Sulfate (SO_4)	311	.21
Chloride (Cl)	54,300	49.75
Total solids	88,721	100.00
Hydrogen sulfide (H_2S)	-	
Barium (Ba)	Trace	
Specific Gravity	1.061	
pH	7.64	

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Summary of Operations

George Sheehan Ellis unit project, Greenwood County, Kans.

Location - Secs. 22, 26, and 27, T. 23 S., R. 11 E.
Sand flooded - Bartlesville
Depth to top of sand - 1940 feet
Average net sand thickness - 17 feet
Productive area - 375 acres
Area flooded - 140 acres
Well pattern - 5-spot (660 by 660 feet)
Type of water - brine
Type of system - open
First injection - August 1955
First oil increase - March 1956
Status - active
Gravity of oil - 38° API.
Viscosity of oil - 41 sec. at 100°F.

Oil produced by years, barrels

1925.... 2,655	1934.... 28,047	1943.... 12,770	1952.... 9,895
1926.... 9,312	1935.... 22,488	1944.... 12,070	1953.... 9,148
1927.... 28,314	1936.... 19,525	1945.... 11,460	1954.... 9,155
1928.... 21,972	1937.... 19,882	1946.... 10,830	1955.... 8,453
1929.... 39,952	1938.... 15,384	1947.... 10,161	1956.... 95,516
1930.... 31,327	1939.... 13,920	1948.... 10,904	1957.... 122,448
1931.... 24,231	1940.... 12,408	1949.... 11,285	1958.... 83,401
1932.... 22,232	1941.... 12,409	1950.... 10,540	1959.... 104,733
1933.... 18,333	1942.... 12,887	1951.... 10,180	

Summary of waterflood performance

Years	Acres flooded	Active input wells	Active oil wells	Cumulative oil recovery, bbl. per acre	Cumulative water-injected: oil-produced ratio
Dec. 31, 1955.....	10	1	1	---	---
Dec. 31, 1956.....	20	1	2	852	2.8
Dec. 31, 1957.....	20	1	2	1,771	2.3
Dec. 31, 1958.....	60	4	6	898	4.4
Dec. 31, 1959.....	140	13	14	1,041	4.6

Data to Jan. 1, 1960

	Barrels
Primary oil recovered, estimated	752,526
Primary oil recovered per acre (270 acres)	2,787
Oil recovered by waterflooding	145,701
Oil recovered per acre by waterflooding (140 acres)	1,041
Total oil recovered	898,227
Total oil recovered per acre (270 acres)	3,327
Total water injected	675,796
Water produced beginning March 1956	210,448

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Monthly record of water injected and oil and water produced, barrels

	1955			1956		
	Water injected	Oil produced	Water produced	Water injected	Oil produced	Water produced
January.....	- -	- -	- -	3,261	- -	- -
February.....	- -	- -	- -	2,554	- -	- -
March.....	- -	- -	- -	3,303	465	15
April.....	- -	- -	- -	2,899	450	15
May.....	- -	- -	- -	3,037	620	15
June.....	- -	- -	- -	2,870	750	16
July.....	- -	- -	- -	2,392	1,395	22
August.....	368	- -	- -	2,839	2,015	0
September....	2,757	- -	- -	2,606	1,950	15
October.....	2,857	- -	- -	2,915	2,620	16
November.....	2,876	- -	- -	3,019	2,535	186
December.....	2,991	- -	- -	3,441	4,247	186
Total.....	11,849	- -	- -	35,136	17,047	486

	1957			1958		
January.....	2,620	3,937	955	2,836	775	2,790
February.....	2,729	2,800	1,456	2,045	700	3,651
March.....	2,992	1,581	2,592	5,179	682	4,805
April.....	2,827	1,530	2,508	2,855	630	3,600
May.....	2,911	1,504	2,666	3,349	744	4,340
June.....	3,204	1,350	2,700	2,411	660	4,326
July.....	3,096	1,271	2,852	3,576	775	3,937
August.....	3,270	1,085	3,069	15,925	1,907	4,151
September....	3,007	900	3,150	26,968	2,640	4,776
October.....	2,794	837	2,759	27,420	2,635	4,960
November.....	2,867	780	2,700	30,198	2,775	4,332
December.....	3,090	806	2,790	32,119	3,519	5,503
Total.....	35,407	18,381	30,197	154,881	18,442	51,171

	1959		
January.....	20,674	3,658	6,033
February.....	23,819	3,122	6,264
March.....	22,713	5,623	6,405
April.....	21,127	5,010	6,039
May.....	17,612	5,208	6,336
June.....	25,445	7,350	5,694
July.....	49,188	10,323	7,642
August.....	42,604	10,606	10,782
September....	47,278	10,350	12,600
October.....	48,842	10,695	16,774
November.....	53,963	10,710	19,380
December.....	65,618	9,176	24,645
Total.....	438,883	91,831	128,594

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Sinclair Oil & Gas Co. Browning Unit Project

The Sinclair Oil & Gas Co. Browning unit waterflood consists of seven leases including 1,120 acres, of which approximately 850 acres are oil productive. Water injection in 2 wells was started in October 1949, and by February 1950 a pilot flood, consisting of 7 input wells on 70 acres, was completed. In July 1953, the project had 18 input wells and 71 active oil wells, with 180 acres under flood. However, only a limited supply of water was available for injection during the early life of the flood, and no increase in oil production was noticed until 1954. In 1955, the supply of injection water was augmented with Arbuckle water, and the project was expanded. By the end of 1959, the project included 708 productive acres, as shown in figure 5.

The formation flooded is the Bartlesville sand which, in this area, is at an average depth of 2,300 feet and has an average effective thickness of 43 feet. The field lies in a definite shoestring trend of the Bartlesville sand that apparently was deposited as an offshore bar. Average reservoir characteristics reported by Wright6/ are: Porosity, 19 percent; permeability to air, 35 millidarcys; original water saturation, 30 percent; original formation volume factor, 1.2; quality factor (net pay to gross pay), 74 percent; and gravity of oil, 40° to 41° API. A representative electric log and the results of typical core analysis are shown in figure 6.

History Before Flooding

The discovery well of the Browning field was completed early in 1924. By 1926 most of the field, covering 850 productive acres, had been developed on a 10-acre spacing pattern. Primary oil production from the leases reached a yearly peak of approximately 2 million barrels in 1926. During the succeeding years, the rate of decline was rapid, but typical of Bartlesville gas-expansion reservoirs produced by unrestricted methods.

In 1928, an attempt was made to arrest the production decline by starting a gas-injection project on some of the leases. The gas drive resulted in only a slight increase over the normal rate of production.

The composite production history of the unit, showing the normal rate of decline during primary and gas-injection methods to an economic limit of 150 barrels of oil a day, and the status of the wells on December 31, 1959 are shown in figure 5. An estimated 9,374,000 barrels of oil, or 11,029 barrels per acre, would have been recovered to an economic limit by primary methods from 850 productive acres, and approximately 1,308,000 barrels, or 1,539 barrels per acre of additional oil was recovered from gas injection.

Method of Completing and Operating Wells

The original oil wells in the field were drilled with cable tools. An intermediate string of 8 5/8-inch casing was set below the Douglas sand, and

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6/ Wright, F. F., Effects of Rate of Performance in Browning Unit Water Flood: Jour. Inst. Petrol. Technol., October 1958, pp. 12-13.

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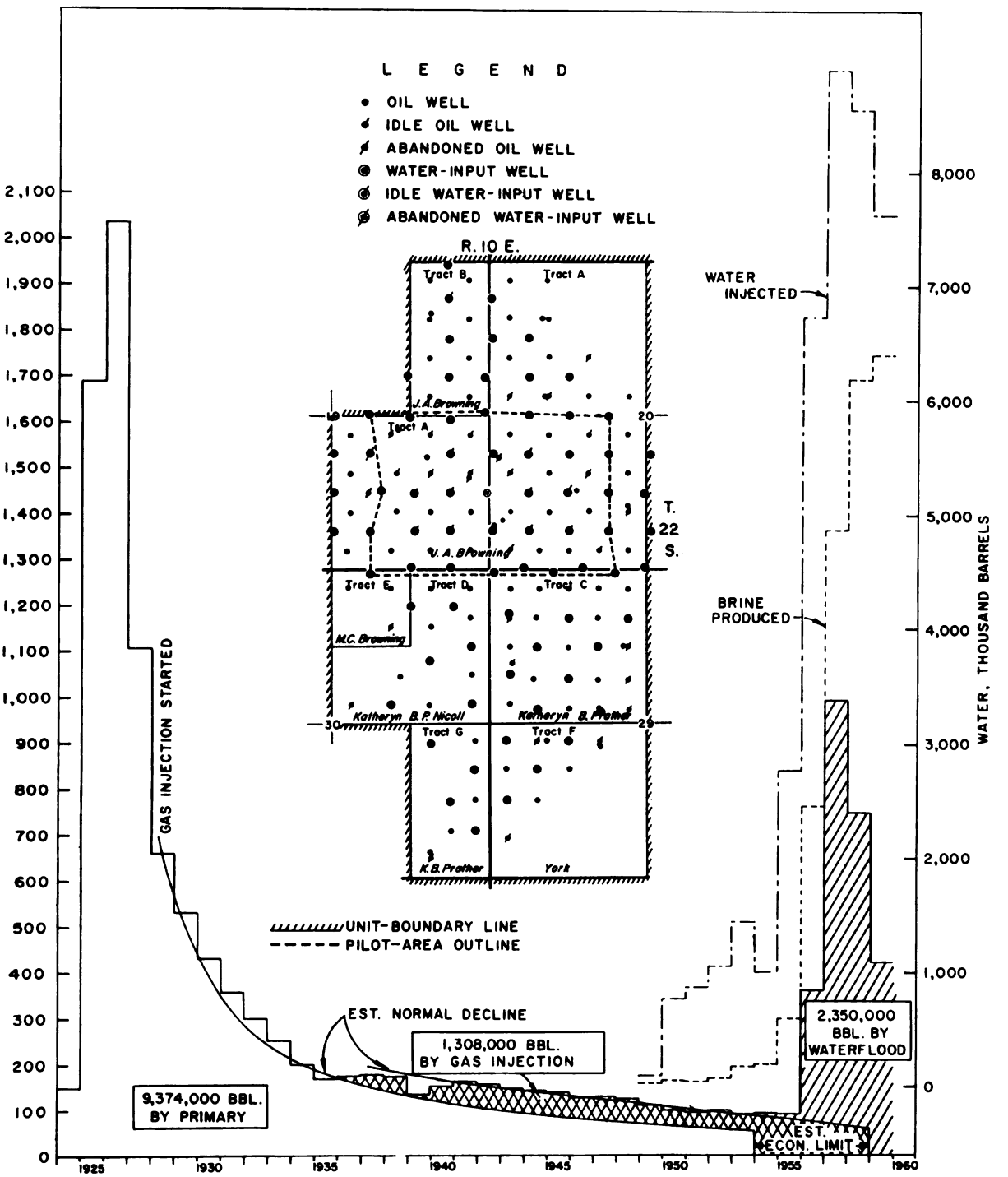

FIGURE 5. - Map and History of Production of Sinclair Oil & Gas Co. Browning Unit Project, Greenwood County, Kans., Jan. 1, 1960.

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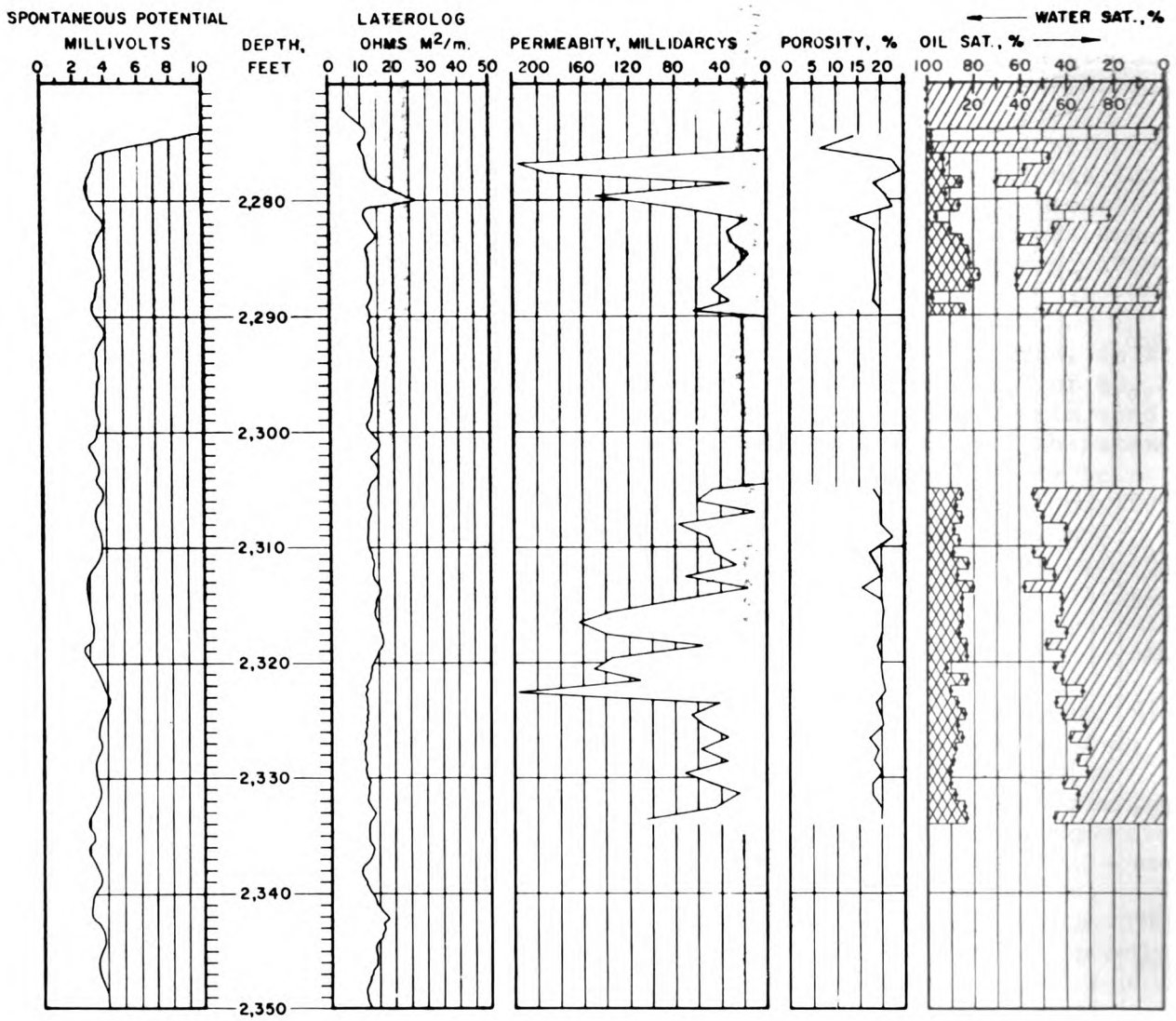

FIGURE 6. - Representative Electric Log and Core Analysis of Bartlesville Sand, Sinclair Oil & Gas Co. Browning Unit Project, Greenwood County, Kans.

drilling was continued into the Bartlesville sand. In many wells a string of 6 5/8-inch casing was set at the top of the sand, and in other wells the casing was seated in the shale section above the sand. The strings of casing were not cemented. The wells were shot with 1 quart of nitroglycerin per foot. The wells were equipped with rods and tubing and were pumped by central power units.

At the start of the pilot flood, several oil-producing and gas-injection wells were converted to input wells. The oil wells were converted for water injection by pulling the rods and tubing, running a scraper to clean the casing wall, and cleaning out the hole to bottom. When the original well was

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was completed with the casing set above the sand, a 5½-inch liner was set at the top of the sand and cemented with 25 to 75 sacks of cement. When the casing in the old well was set at the top of the sand, it was perforated or ripped and squeezed with 50 to 100 sacks of cement. A string of 2 7/8-inch cement-lined tubing and a packer were run to protect the casing from corrosion. Gas-injection wells were converted to water-input wells in a similar manner. New water input wells were drilled with rotary drilling equipment. In these wells, approximately 200 feet of 8 5/8-inch surface casing was set and cemented with approximately 125 sacks of cement. A 7 7/8-inch hole then was drilled to the top of the sand, and a 3½-inch core was taken of the entire sand section. The core hole then was reamed to full-hole size, and a string of 5- or 5½-inch casing was set and cemented at the top of the sand with 100 to 150 sacks of cement. Cable tools were used to drill out the cement plug and clean the hole to bottom. The sand section was acidized with 500 gallons of mud acid, and the hole again was cleaned to bottom. A protective string of 2 7/8-inch cement-lined tubing was run to protect the casing from corrosion. New oil wells were drilled and completed in the same manner as input wells, except the cement-lined tubing was replaced with equipment for pumping.

During the flood, the central power units were replaced with individual pumping units as soon as the volume of fluid produced was greater than the capacities of the pumps powered by the central units. Originally, the individual units were powered with gas engines. Later the flood was electrified, and the gas engines were replaced with electric motors.

Source and Treatment of Water

At the start of the pilot flood in October 1949, brine for flooding was supplied from four Douglas-water sand wells in a closed-injection system. As the flood was extended, the closed system was replaced by a pressure plant equipped with centrifugal pumps and a slow sand filter. An 8-inch cement-asbestos line was laid to the Verdigris river to augment the supply of water available for injection. The Douglas-sand water and produced brine were mixed and pumped through the filter. Water from the Verdigris river was filtered through two gravity-feed rapid sand filters that were connected directly to the suction manifold of the high-pressure injection pumps.

During 1955, the supply of water available from the Douglas wells and the Verdigris river became inadequate, and an Arbuckle-supply water well was drilled. The volume of Arbuckle water proved adequate, and the use of all other sources of makeup water was discontinued.

In February 1956, a new pressure plant, equipped with 7 triplex pumps, was completed. Four pumps inject produced brine, and three pumps injected Arbuckle water. The slow sand-filter system was replaced by four closed-type rapid filters. The sand-filter "tub" (the two lower rings of a 55,000 barrel tank) was cleaned out, and the three sections were used as a receiving tank, a clear-water tank, and a backwash tank, respectively. The new water-treating and pumping equipment are shown in figure 7.

Produced brine from two tank batteries flows by gravity into a skimmer tank, where the water level is controlled by a float valve. Accumulated oil

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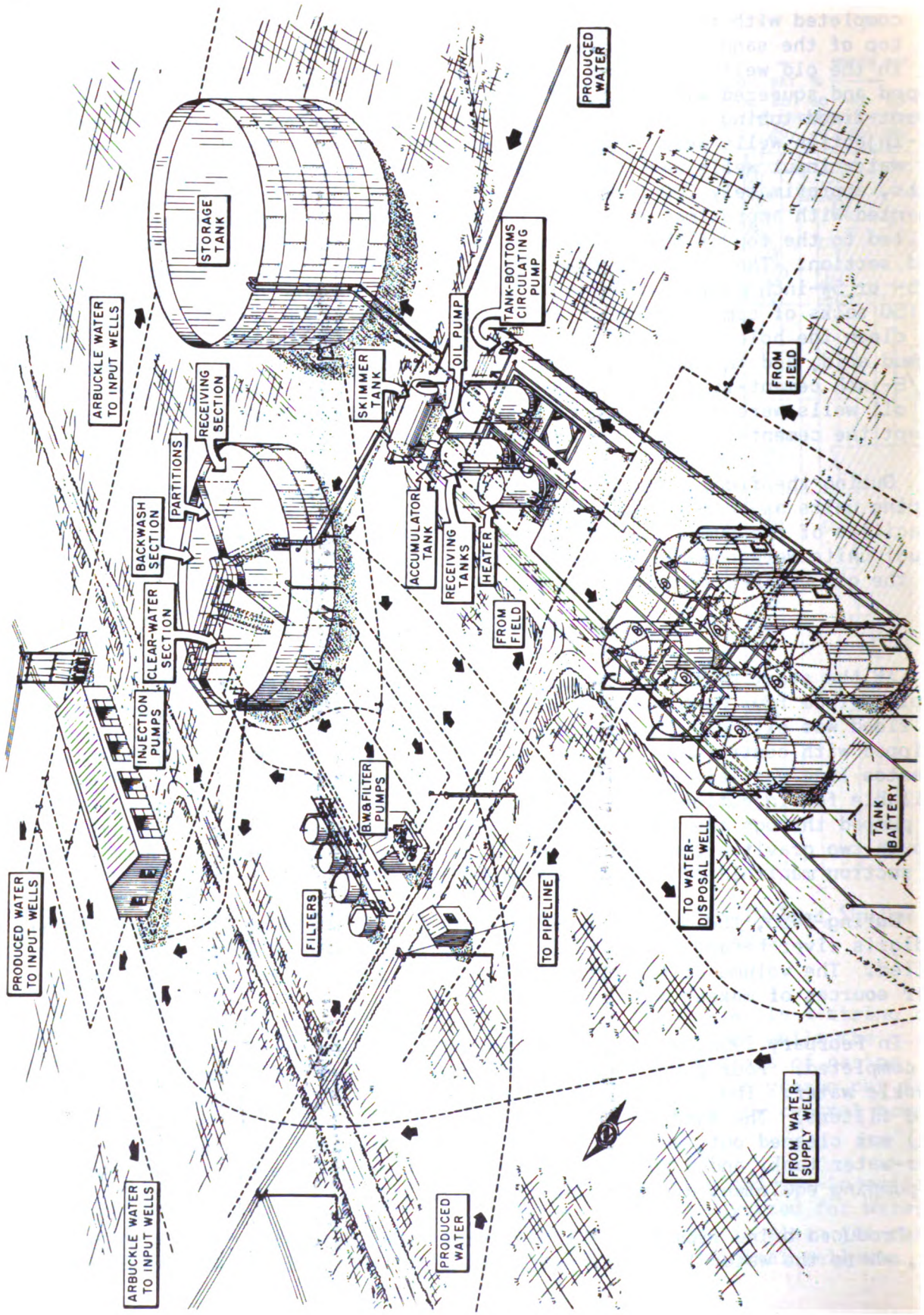

FIGURE 7. - Water-Treating Plant of Sinclair Oil & Gas Co. Browning Unit Project, Greenwood County, Kans

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in the tank flows into a small accumulator tank and is recycled into the heater-treater. From the skimmer tank the water flows by gravity into the receiving section of the tub. Produced water from a third tank battery flows directly into the receiving section. The water level in the receiving section is controlled by a float valve. When the water level becomes too high, the flow to the receiving section is shut off, and the excess water flows into a 35,000 barrel storage tank. The volume of water in the storage tank is controlled by an automatic valve. Surplus water flows by gravity into an Arbuckle water-disposal well.

From the receiving section the water flows by gravity to the filter pumps and is pumped through four closed-type rapid filters into the clear-water section of the tub. The filters are backwashed daily with water from the clear-water section. The backwash water is pumped into the backwash-water section of the tub. The level in the clear-water section is controlled by a hydrostatic-head pressure switch, which controls the filter pumps. Water flows by gravity from the clear-water section into the produced-water manifold at the pressure plant. The water is pumped, at a plant pressure of 860 p.s.i., through injection lines to input wells north of the plant.

Water from the Arbuckle well is pumped through a closed system directly to the Arbuckle-water manifold at the plant. The water is pumped at a plant pressure of 860 p.s.i. to input wells south and west of the plant. A booster pump increases the injection pressure to 1,100 p.s.i. for 12 input wells in the extreme south end of the flood.

Except for corrosion inhibitors, no chemicals are added either to the Arbuckle water or the produced brine. The Arbuckle water is treated daily with 10 gallons of Sinclair corrosion inhibitor P-456, and the filtered produced brine is treated daily with 15 gallons of Sinclair corrosion inhibitor P-333. Individual oil wells are treated through the annulus with 2 gallons per week of Sinclair Corrosion inhibitor P-400. Mineral analyses of the injection waters and brine from an oil well, in the area of Arbuckle water injection, are shown in table 2. The characteristics of the water from the oil well are similar to those of the produced brine from the plant. The presence of barium in the waters, the high amount of sulfate in the Arbuckle water, and the low amount of barium in the water from the oil well indicate that some barium sulfate may be precipitating. This may be the cause of plugging in some oil wells.

Results of Flooding

Results of waterflooding on the Browning Unit are shown in figure 5 and in the Summary of Operations. To December 31, 1959, approximately 2,350,000 barrels of oil, in addition to that expected by primary production and gas injection, was recovered by injecting about 40 million barrels of water. This equals a cumulative water-injected to oil-produced ratio of 17 to 1 and a recovery of 3,320 barrels per acre from the 708 developed acres.

During the early life of the pilot flood, from 1949 to 1954, the response to water injection was slow because of an inadequate supply of water. However,

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TABLE 2. - Mineral analyses of injection waters and brine from oil well, Sinclair Oil & Gas Co. Browning Unit, Greenwood County, Kans.

Ion or radical	Arbuckle water		Produced brine from			
			Plant		Oil Well	
	Milligrams per liter	Reacting values, percent Palmer	Milligrams per liter	Reacting values, percent Palmer	Milligrams per liter	Reacting values, percent Palmer
Calcium (Ca).....	2,900	7.89	3,500	6.84	3,400	6.73
Magnesium (Mg).....	700	3.14	972	3.12	900	2.93
Sodium (Na).....	16,400	38.97	23,500	40.04	23,400	40.34
Carbonate (CO_3).....	0	0	0	0	0	0
Bicarbonate (HCO_3).....	173	.16	220	.14	251	.16
Sulfate (SO_4).....	1,914	2.17	1,087	.88	1,155	.95
Chloride (Cl.).....	31,000	47.67	44,400	48.98	43,700	48.89
Total Solids.....	53,087	100.00	73,679	100.00	72,806	100.00
Hydrogen Sulfide (H_2S).....	Present		-----		-----	
Barium (Ba).....	212		231		36	
Specific Gravity.....	1.036		1.055		1.050	
pH.....	7.52		7.48		7.21	

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an Arbuckle water-supply well drilled in 1955 provided an adequate source of water, and the injection rates were increased from 2,000 to 3,000 barrels per day to 6,000 to 8,000 barrels per day. This accelerated rate of injection immediately augmented the rate of water production, and in approximately 3 months, resulted in an appreciable increase in the rate of oil production. Since 1955, the development of the unit waterflood has been expanded to cover nearly all the productive area.

During November 1959, a peripheral-pattern flood was begun in the pilot-flood area (fig. 5), and oil wells producing large volumes of fluid were shut in. Although the new flood pattern has been in operation for only a short time, a slight increase in oil production from some wells in the area has been observed.

Summary of Operations

Sinclair Oil and Gas Co.: Browning unit project

Location - Secs. 19, 20, 29 and 30, T. 22 S., R. 10 E.
Sand flooded - Bartlesville
Depth to top of sand - 2,300 feet
Average net sand thickness - 43 feet
Productive area - 850 acres
Area flooded - 708 acres
Well pattern - 5-spot (660 by 660 feet)
Type of Water - brine
Type of systems - open & closed
First injection - Oct. 1949
First oil increase - Jan. 1954
Status - active
Gravity of oil - 41.1° API
Viscosity of oil - 38 sec. at 100°F.

Summary of waterflood performance

Years	Acres flooded	Active input wells	Active oil wells	Cumulative oil recovery barrels per acre	Cumulative water-injected-oil-produced ratio
Dec. 31, 1949.....	20	2	72	- -	- -
Dec. 31, 1950.....	70	7	72	- -	- -
Dec. 31, 1951.....	110	11	75	- -	- -
Dec. 31, 1952.....	170	17	70	- -	- -
Dec. 31, 1953.....	180	18	71	- -	- -
Dec. 31, 1954.....	180	18	70	43	681
Dec. 31, 1955.....	420	31	64	46	415
Dec. 31, 1956.....	508	51	68	607	48
Dec. 31, 1957.....	550	65	76	2,247	19
Dec. 31, 1958.....	708	72	79	2,724	17
Dec. 31, 1959.....	708	60	72	3,320	17

Data to Jan. 1, 1960

	Barrels
Estimated ultimate oil recovery by primary methods.....	9,374,225
Oil recovered per acre by primary (850 acres).....	11,029
Estimated ultimate oil recovery by gas injection.....	1,307,868
Oil recovered per acre by gas injection (850 acres).....	1,539
Oil recovered by waterflooding.....	2,350,210

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Data to Jan. 1, 1960 (con.)

	Barrels
Oil recovered per acre by waterflooding (708 acres)	3,320
Total oil recovered	13,032,303
Total recovery per acre (850 acres)	15,332
Total water injected	39,796,825
Water produced beginning June 1, 1949	21,099,481

Oil and water produced and water injected, by years, barrels.

	Oil produced				Water	
	By primary	By gas injection	By waterflood	Total	Injected	Produced
1924....	148,591	- -	- -	148,591	- -	- -
1925....	1,689,749	- -	- -	1,689,749	- -	- -
1926....	2,033,826	- -	- -	2,033,826	- -	- -
1927....	1,106,762	- -	- -	1,106,762	- -	- -
1928....	661,379	- -	- -	661,379	- -	- -
1929....	495,000	37,310	- -	532,310	- -	- -
1930....	385,000	45,831	- -	430,831	- -	- -
1931....	315,000	42,604	- -	357,604	- -	- -
1932....	265,000	34,462	- -	299,462	- -	- -
1933....	225,000	27,997	- -	252,997	- -	- -
1934....	198,933	- -	- -	198,933	- -	- -
1935....	169,985	- -	- -	169,985	- -	- -
1936....	160,000	15,154	- -	175,154	- -	- -
1937....	145,000	33,386	- -	178,386	- -	- -
1938....	135,000	36,665	- -	171,665	- -	- -
1939....	125,000	9,216	- -	134,216	- -	- -
1940....	115,000	37,227	- -	152,227	- -	- -
1941....	107,000	56,392	- -	163,392	- -	- -
1942....	99,000	57,027	- -	156,027	- -	- -
1943....	93,000	55,371	- -	148,371	- -	- -
1944....	88,000	56,122	- -	144,122	- -	- -
1945....	83,000	54,768	- -	137,768	- -	- -
1946....	78,000	49,611	- -	127,611	- -	- -
1947....	74,000	54,222	- -	128,222	- -	- -
1948....	71,000	53,341	- -	124,341	- -	- -
1949....	68,000	44,313	- -	112,313	97,392	34,994
1950....	65,000	34,950	- -	99,950	761,601	52,218
1951....	62,000	33,819	- -	95,819	869,143	49,055
1952....	57,000	40,693	- -	97,693	1,049,739	72,873
1953....	55,000	35,387	- -	90,387	1,440,628	180,017
1954....	- -	85,000	7,662	92,662	1,000,454	193,453
1955....	- -	80,000	11,579	91,579	2,767,128	596,625
1956....	- -	72,000	289,120	361,120	6,738,700	2,450,744
1957....	- -	68,000	927,704	995,704	8,894,820	4,872,408
1958....	- -	57,000	692,796	749,796	8,548,520	6,189,384
1959....	- -	- -	421,349	421,349	7,628,700	6,407,710
Total...	9,374,225	1,307,868	2,350,210	13,032,294	39,796,825	21,099,481

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Cities Service Oil Co. Teter Unit Project

In November 1947, the Cities Service Oil Co. started a pattern-type pilot flood by converting 9 oil wells to input wells in sec. 16, T. 23 S., R. 9 E. Although a small increase in oil production was noticed in several oil wells about 1 year after injection began, the response to water injection was slow, and it was 1951 before the pilot flood was expanded. By the end of 1959, the project had been extended to cover 850 productive acres in secs. 10, 11, 14, 15, and 16, T. 23 S., R. 9 E., as shown in figure 8.

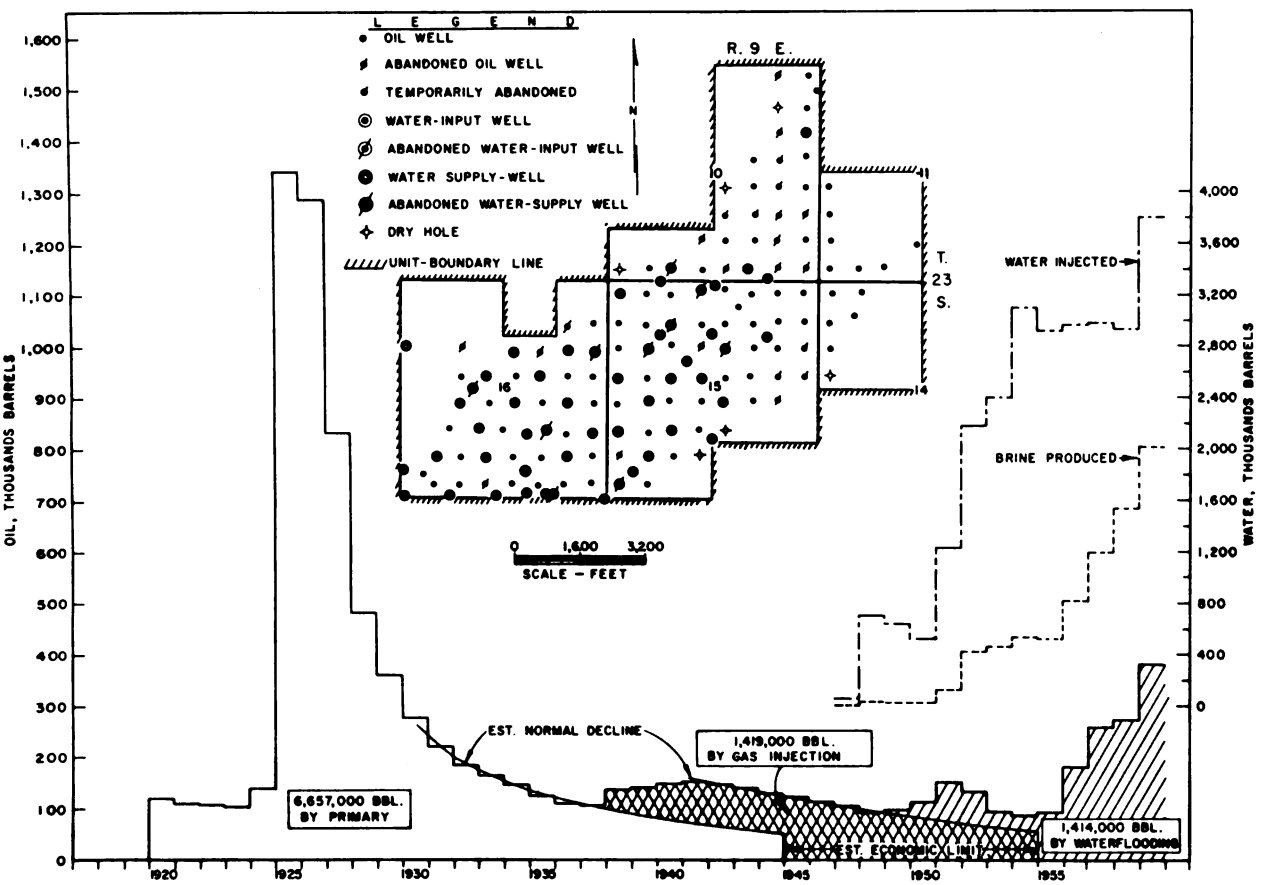

FIGURE 8. - Map and History of Production of Cities Service Oil Co. Teter Unit Project, Greenwood County, Kans., Jan. 1, 1960.

The formation flooded is the Bartlesville sand which, in this area, is at an average depth of 2,525 feet and has an average effective thickness of 48 feet. The sand is a shoestring type, the origin and geology of which have been described in detail by Bass.7/ Analyses of cores taken before flooding indicated an average porosity of 18 percent, ranging from 13 to 22 percent,

7/ Bass, N. W., Origin of the Shoestring Sands of Greenwood and Butler Counties, Kans.: Kansas Geol. Survey Bull. 23, 1936, 135 pp.

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and the average oil saturation was 44 percent. Figure 9 depicts the results of analyses of a representative core taken in 1951.

History Before Flooding

The discovery well on the properties now included in the Teter unit was completed in July 1919. By 1927, all the properties covering 1,150 productive acres had been developed on a 10-acre well-spacing pattern. Oil production from the leases reached a yearly peak of approximately 1,300,000 barrels in 1925. During the succeeding years, the rate of decline was rapid, typical of Bartlesville gas-expansion reservoirs produced by unrestricted methods.

In December 1936, the properties were unitized for gas injection. By 1937, when gas injection was begun, the annual rate of oil production had declined to a low of approximately 105,000 barrels. The response to gas injection was gradual, and in 1941, the annual rate of production had increased to about 151,000 barrels. The rate of production gradually decreased to approximately 93,000 barrels in 1948.

The composite production history of the unit, showing the normal rate of decline during primary and gas-injection methods to an economic limit of 150 barrels a day, and the status of the wells on December 31, 1959 are depicted in figure 8. An estimated 6,657,000 barrels of oil, or 5,789 barrels per acre, would have been recovered by primary methods to the economic limit and an additional 1,419,000 barrels, or 1,234 barrels per acre, was recovered by gas injection. The estimated total oil recovery before waterflooding was 8,076,000 barrels, or 7,023 barrels per acre for the 1,150 productive acres.

Method of Completing and Operating Wells

The original wells in the Teter field were drilled with cable tools through the Bartlesville sand. They were completed with 6 5/8-inch casing set, but not cemented, at the top of the sand. The wells were shot with 2 to 3 quarts of nitroglycerin per foot of pay sand and were cleaned out. Some wells flowed for several years after completion. Later the wells were pumped by central power units. Since 1951, all the central power units in the flood area have been replaced by electric-powered individual pumping units.

Oil wells completed after 1955 were drilled with rotary tools through the Bartlesville sand. Seven-inch casing was set on bottom and was cemented with 100 sacks of cement. The casing was perforated opposite the pay zone, and the sand was hydraulically fractured, through the perforations, with 10,000 to 20,000 pounds of sand and water.

When the pilot flood was started in 1947, nine oil wells were converted to water-input wells. The procedure in converting the wells was to pull the rods and tubing, set a plug, and cement the 6 5/8-inch casing with 50 to 100 sacks of cement, reshoot the sand with nitroglycerin, and clean out the well bore. New input wells were drilled with rotary tools. Approximately 200 feet of 8 5/8-inch surface casing was set and cemented with 85 packs of cement. A 6 5/8-inch hole then was drilled to the top of the sand at an average depth of

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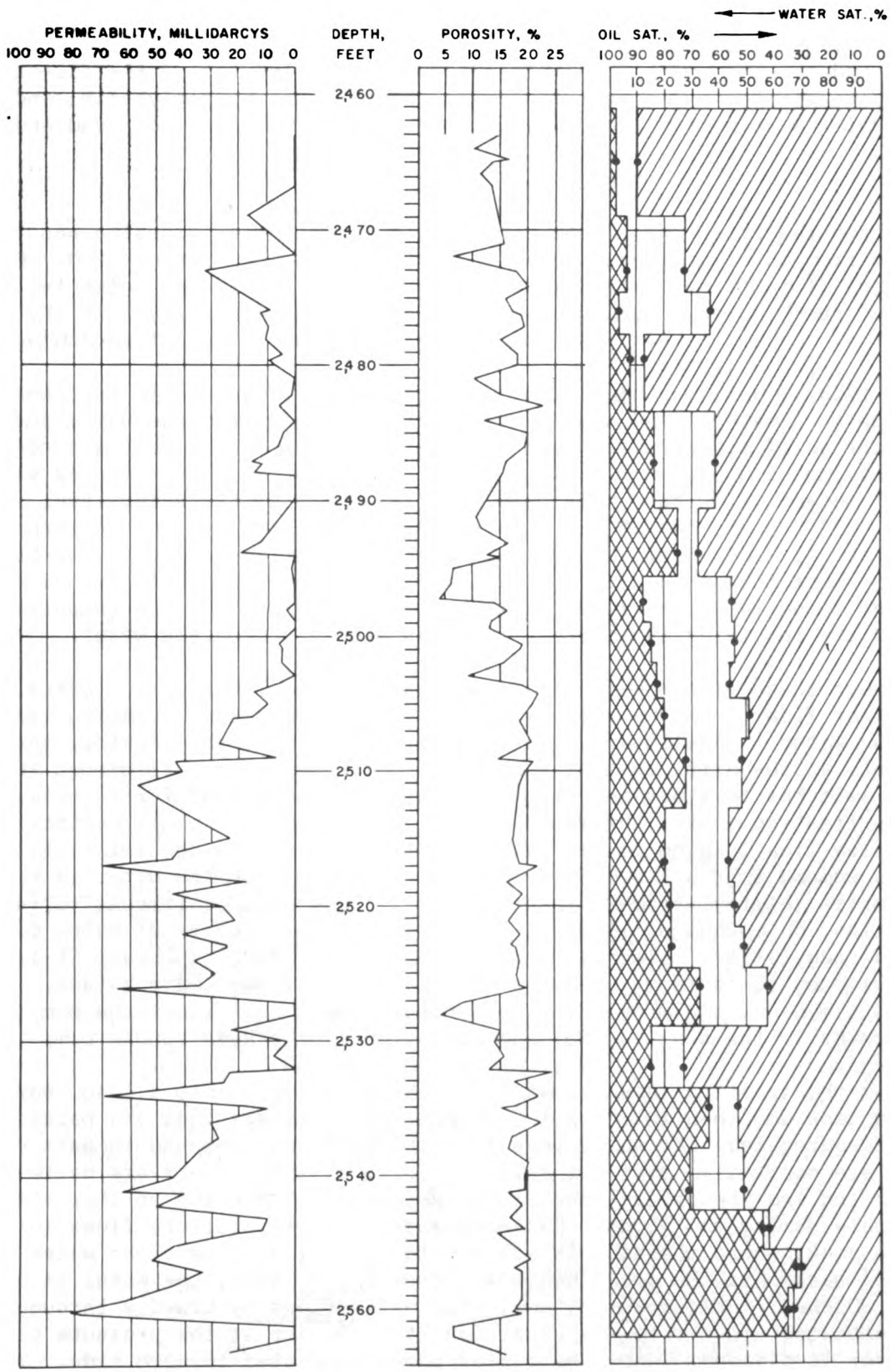

FIGURE 9. - Representative Core Analysis of Bartlesville Sand, Cities Service Oil Co. Teter Unit Project, Greenwood County, Kans.

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2,525 feet, and the entire sand section was cored. A string of 5½-inch casing was set and cemented with 100 sacks of cement near the top of the oil-saturated sand. Some earlier wells were shot with 80 quarts of nitroglycerin, and some recent wells were hydraulically fractured with 25,000 pounds of sand and water.

Source and Treatment of Water

During the first three years of operation, brine for flooding was obtained from three water-supply wells completed in the Douglas sand. By 1951, the source of water had become inadequate, and the supply was augmented by impounded fresh water. During a drouth in 1952, the water level in the lake became low, and again there was only a limited amount of water for injection.

In 1953, a well was completed in the Arbuckle limestone to supplement this supply of water. The supply of Arbuckle water proved adequate, and all other sources of makeup water were abandoned. The Arbuckle well was completed with a string of 8 5/8-inch casing set at 2,976 feet and was cemented with 400 sacks of cement, with open hole to 3,502 feet. The static water level in the well is at 700 feet. A 135-hp. Reda submerged electric pump on 4½-inch steel casing, set at 1,145 feet, delivers brine to the surface and to a 300-barrel receiving tank through a 4-inch cement-asbestos line. Produced brine, collected at three tank batteries, flows by gravity through 6-inch cement-asbestos lines to the receiving tank, where it mixes with the Arbuckle water.

Figure 10 shows the water-treating plant of the Teter unit project. The mixed water flows from the receiving tank into a 500-barrel aerating tank, where the water is agitated by two large blowers. From the aerator, the water flows into a 250-barrel control tank, equipped with electrical probes that actuate switches to start and stop the raw-water pumps that force the water into the treating tank. The water level in the control tank is controlled by an overflow line leading to the receiving tank. From the control tank, the water is pumped into a 1,600-barrel treating tank, where the water is treated by automatic chemical feeders that add daily 200 pounds of ferrous sulfate for coagulation, 50 pounds of lime for pH control, and 20 quarts of Nalco 600 for improved coagulation. Electrical probes in the treating tank keep it from overflowing by controlling operation of the pumps at the control tank. If the level is too high, the probes in the control tank cannot start the pumps. Other probes in the tank control the operation of the Reda supply pump.

From the treating tank, the water flows by gravity into a 1,400-barrel settling tank and then into six 100-barrel, open filters that are packed with sand and aggregate. The water levels in the settling tank and in each of the filters are controlled by float valves. Three of the filters are backwashed each morning and the other three are backwashed each evening so that all six may operate during the night. Backwash water from the filters flows into a backwash tank, where the dirt is allowed to settle, and the clear water then is pumped back into the treating tank. From the filters, the water is pumped into an 800-barrel clear-water tank. The water flows by gravity through two cement-asbestos lines from the clear tank to a header at the pressure plant. The header is divided, with two triplex pumps connected to each side. The water is pumped through cement-lined distribution lines to the input wells at

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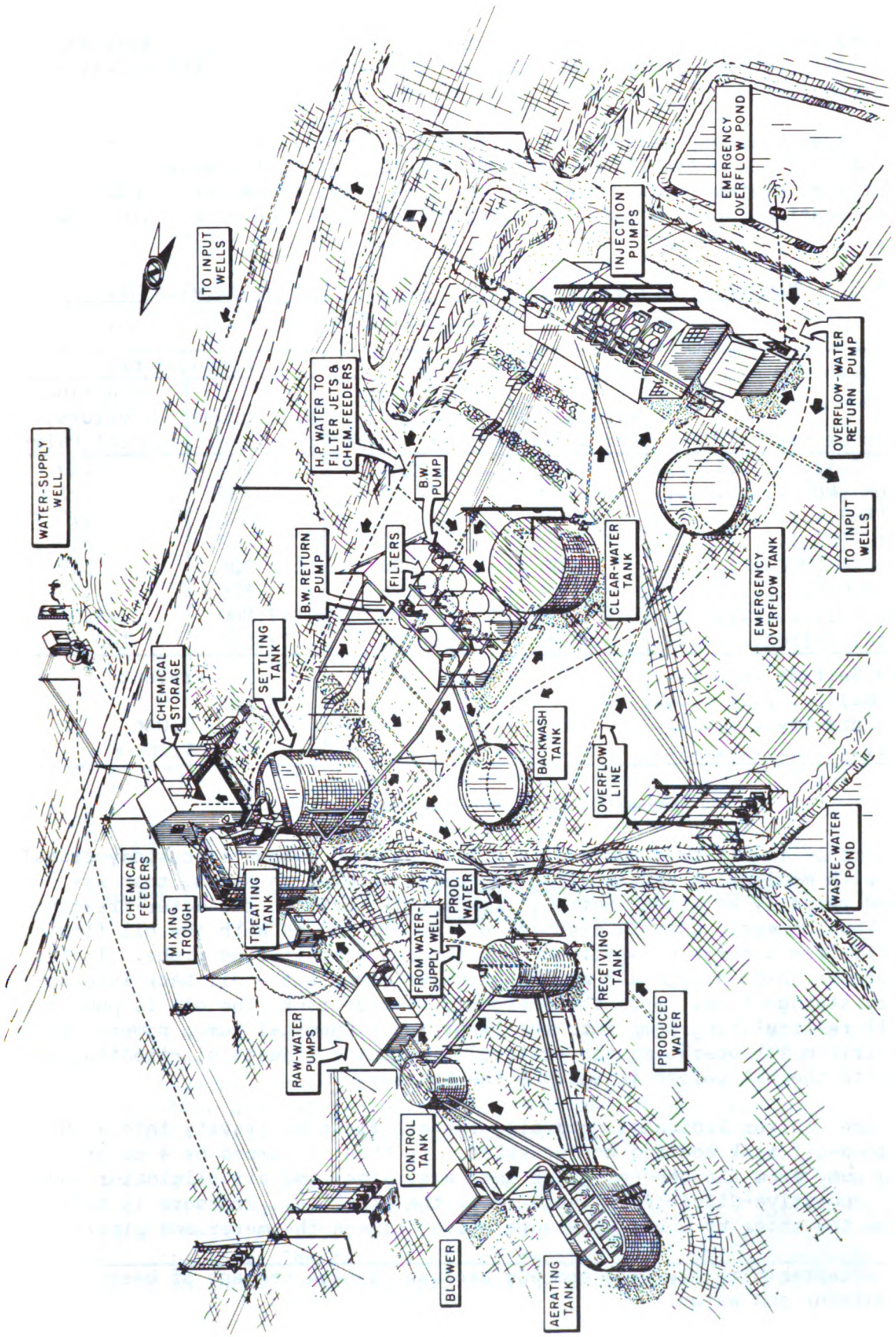

FIGURE 10. - Water-Treating Plant of Cities Service Oil Co. Teter Unit Project, Greenwood County, Kans.

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a plant pressure of approximately 700 p.s.i. Probes in the clear tank and automatic oil and pressure controls on the line pumps control the operation of the pressure plant.

As a precautionary measure, lines from the control, receiving, and settling tanks are connected to an overflow tank to control the water level when the electrical system fails. From the overflow tank, the water is pumped back into the treating tank. Mineral analyses of the injection waters are shown in table 3.

TABLE 3. - Mineral analyses of injection waters, Cities Service Oil Co., Teter unit project, Greenwood County, Kans.

Ion or radical	Arbuckle		Produced brine	
	Milligrams per liter	Reacting values, Percent Palmer	Milligrams per liter	Reacting values, Percent Palmer
Calcium (Ca).....	2,420	8.45	3,100	5.69
Magnesium (Mg).....	480	2.76	730	2.21
Sodium (Na).....	12,700	38.79	26,300	42.10
Carbonate (CO_3).....	0	0	0	0
Bicarbonate (HCO_3).....	206	.24	306	.19
Sulfate (SO_4).....	2,049	2.98	356	.27
Chloride (Cl).....	23,700	46.78	47,800	49.54
Total Solids.....	41,555	100.00	78,592	100.00
Hydrogen Sulfide (H_2S)....	Present		Present	
Barium (Ba).....	0		0	
Specific gravity.....	1.032		1.046	
pH.....	6.79		7.10	

Automatic Custody-Transfer System

Figure 11 is a flow diagram of a self-contained automatic custody-transfer system, with monitoring and metering equipment mounted on skids, that was installed recently at a tank battery immediately north of the water-treating plant. The automatic custody transfer of the oil begins with the oil flowing by gravity from a surge or settling tank through a monitoring probe. If the probe detects "bad" oil,8/ a 3-way motor valve diverts the oil back into an emergency storage tank. From the emergency storage tank, the oil is pumped by a bad-oil recirculating pump into the treater. A chemical pump, powered by the electric motor operating the recirculating pump, injects oil-treating compounds into the oil before it reaches the treater.

If the monitor indicates good oil, the oil flows by gravity into a 15-barrel good-oil tank mounted on the skids. It then is pumped by a meter-charging pump from the good-oil tank into a strainer and air eliminator and through a positive-displacement meter into the pipeline. Pressure is maintained on the meter by a back-pressure valve between the meter and pipeline

8/ Not acceptable to pipeline company because of high content of basic sediment and water.

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connection. An automatic device samples the pipeline oil at regular intervals and may be checked for basic-sediment and water-content grindout at the convenience of the pipeline gager. The accuracy of the positive-displacement meter is checked each month by a volume-prover tank.

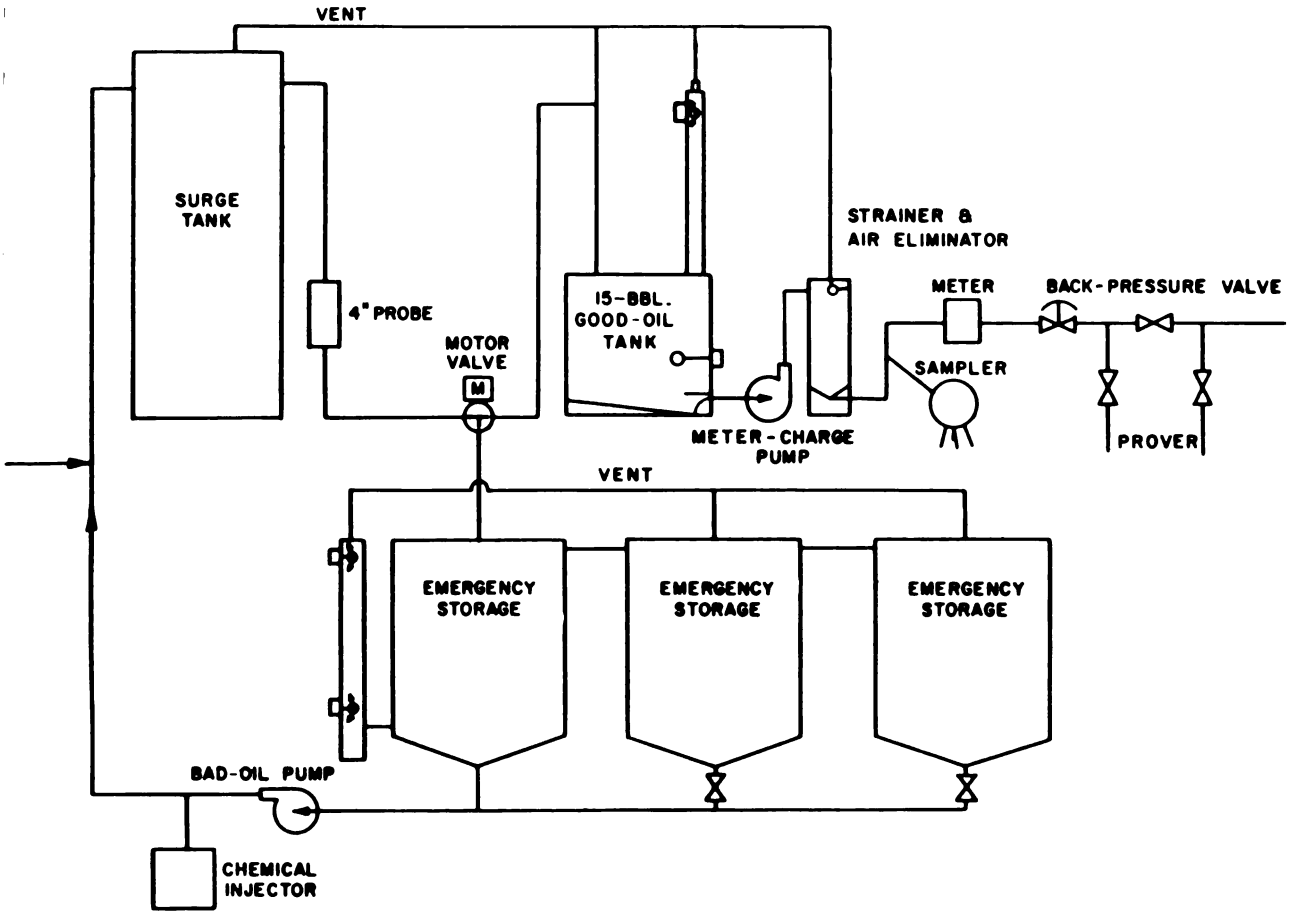

FIGURE 11. - Automatic Custody-Transfer System, Cities Service Oil Co. Teter Unit Project, Greenwood County, Kans.

Results of Flooding

Results of waterflooding on the Teter Unit are shown in figure 8 and in the Summary of Operations. To December 31, 1959, approximately 1,400,000 barrels of oil was gained by injecting about 26 million barrels of water. This equals a cumulative water-injected to oil-produced ratio of 19 to 1, and a recovery of 1,664 barrels per acre from the 850 developed acres.

Response to water injection during the early life of the flood was slow because of a limited supply of water available for injection. Expansion of the pilot flood began in 1951, but it was 1955 before a favorable response to flooding was attained. The rate of oil production has increased rapidly since 1955, reaching an annual peak of approximately 381,000 barrels in 1959.

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Summary of Operations

Cities Service Oil Co. Teter unit project

Teter Field, Greenwood County, Kans.

Location - Secs. 10, 11, 14, 15, and 16, T. 23 S., R. 9 E.
Sand flooded - Bartlesville
Depth to top of sand - 2,525 feet
Average net sand thickness - 48 feet
Productive area - 1,150 acres
Area flooded - 850 acres
Well pattern - 5-spot (20-acre spacing)
Type of water - brine
Type of system - open
First injection - November 1947
First oil increase - 1949
Status - active
Gravity of oil - 38.6° API
Viscosity of oil - 41 sec. at 100°F

Summary of waterflood performance

Years	Acres flooded	Active input wells	Active oil wells	Cumulative oil recovery barrels per acre	Cumulative water-injected-oil-produced ratio
Dec. 31, 1947.....	200	9	13	- -	- -
Dec. 31, 1948.....	200	9	13	- -	- -
Dec. 31, 1949.....	200	9	13	32	217
Dec. 31, 1950.....	200	9	16	166	57
Dec. 31, 1951.....	435	18	31	248	29
Dec. 31, 1952.....	690	31	47	249	31
Dec. 31, 1953.....	690	33	45	290	39
Dec. 31, 1954.....	690	28	46	329	48
Dec. 31, 1955.....	690	35	71	463	43
Dec. 31, 1956.....	690	34	71	727	33
Dec. 31, 1957.....	736	34	76	1,031	26
Dec. 31, 1958.....	785	37	75	1,315	22
Dec. 31, 1959.....	850	42	74	1,664	19

Data to Jan. 1, 1960

	Barrels
Estimated ultimate oil recovery by primary methods.....	6,656,984
Recovery per acre by primary (1,150 acres).....	5,789
Estimated ultimate oil recovery by gas injection.....	1,419,135
Recovery per acre by gas injection (1,150 acres).....	1,234
Oil recovered by waterflooding.....	1,414,047
Oil recovered per acre by waterflooding (850 acres).....	1,664
Total oil recovered.....	9,490,166
Total oil recovered per acre (1,150 acres).....	8,252
Total water injected.....	26,241,832
Water produced beginning November 1947.....	7,765,263

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Oil and water produced and water injected, by years, barrels.

	Oil produced					
	By primary	By gas injection	By waterflood	Total	Injected	Produced
1919.....	3,299	- -	- -	3,299	- -	- -
1920.....	118,886	- -	- -	118,886	- -	- -
1921.....	110,373	- -	- -	110,373	- -	- -
1922.....	107,433	- -	- -	107,433	- -	- -
1923.....	104,461	- -	- -	104,461	- -	- -
1924.....	137,997	- -	- -	137,997	- -	- -
1925.....	1,344,115	- -	- -	1,344,115	- -	- -
1926.....	1,286,639	- -	- -	1,286,639	- -	- -
1927.....	830,812	- -	- -	830,812	- -	- -
1928.....	480,297	- -	- -	480,297	- -	- -
1929.....	359,715	- -	- -	359,715	- -	- -
1930.....	276,279	- -	- -	276,279	- -	- -
1931.....	219,569	- -	- -	219,569	- -	- -
1932.....	184,160	- -	- -	184,160	- -	- -
1933.....	164,621	- -	- -	164,621	- -	- -
1934.....	145,362	- -	- -	145,362	- -	- -
1935.....	122,782	- -	- -	122,782	- -	- -
1936.....	107,696	- -	- -	107,696	- -	- -
1937.....	105,488	- -	- -	105,488	- -	- -
1938.....	95,000	41,009	- -	136,009	- -	- -
1939.....	85,000	53,937	- -	138,937	- -	- -
1940.....	80,000	65,148	- -	145,148	- -	- -
1941.....	72,000	79,498	- -	151,498	- -	- -
1942.....	60,000	85,393	- -	145,393	- -	- -
1943.....	55,000	82,905	- -	137,905	- -	- -
1944.....	- -	127,610	- -	127,610	- -	- -
1945.....	- -	123,998	- -	123,998	- -	- -
1946.....	- -	113,818	- -	113,818	- -	- -
1947.....	- -	104,417	- -	104,417	52,099	8,648
1948.....	- -	93,402	- -	93,402	707,320	34,310
1949.....	- -	90,000	6,424	96,424	636,009	31,671
1950.....	- -	87,000	26,847	113,847	516,934	27,659
1951.....	- -	76,000	74,793	150,793	1,230,206	123,974
1952.....	- -	70,000	63,425	133,425	2,183,258	426,811
1953.....	- -	65,000	28,801	93,801	2,399,407	471,079
1954.....	- -	60,000	26,714	86,714	3,100,757	536,227
1955.....	- -	- -	92,697	92,697	2,923,350	526,087
1956.....	- -	- -	181,800	181,800	2,971,174	818,605
1957.....	- -	- -	257,664	257,664	2,980,602	1,199,939
1958.....	- -	- -	273,390	273,390	2,734,851	1,540,929
1959.....	- -	- -	381,492	381,492	3,805,865	2,019,324
Total.....	6,656,984	1,419,135	1,414,047	9,490,166	26,241,832	7,765,263

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Wood Oil Co. Wiggins Project

The Wood Oil Co. Wiggins project in secs. 19, 30, and 31, T. 24 S., R. 11 E., and secs. 25 and 36, T. 24 S., R. 10 E., consists of nine leases and totals 1,360 acres, of which 696 acres were oil productive during primary development.

Water injection was started in June 1956 into 3 input wells, and by December 1956 the pilot area contained 13 input wells. Development was rapid and by December 31, 1959 the flood included 28 input wells on 670 productive acres, as shown in figure 12.

The formation flooded, the Cattleman or Wiggins sand, presumably is a lenticular Pennsylvanian sand body in the Cherokee shale. It is found in this area at an average depth of 1,800 feet and has an average net thickness of 15.6 feet. Analyses of 34 cores taken during flood development indicate that the Cattleman sand has an average porosity of 20.2 percent, ranging from 15 to 26 percent, and an average permeability to air of 104 millidarcys, ranging from 0 to 333 millidarcys. The average core water saturation was 55 percent, and the core oil saturation was 20 percent. After flood-pot tests, the oil saturation was 17 percent, and the water saturation was 75 percent. Figure 13

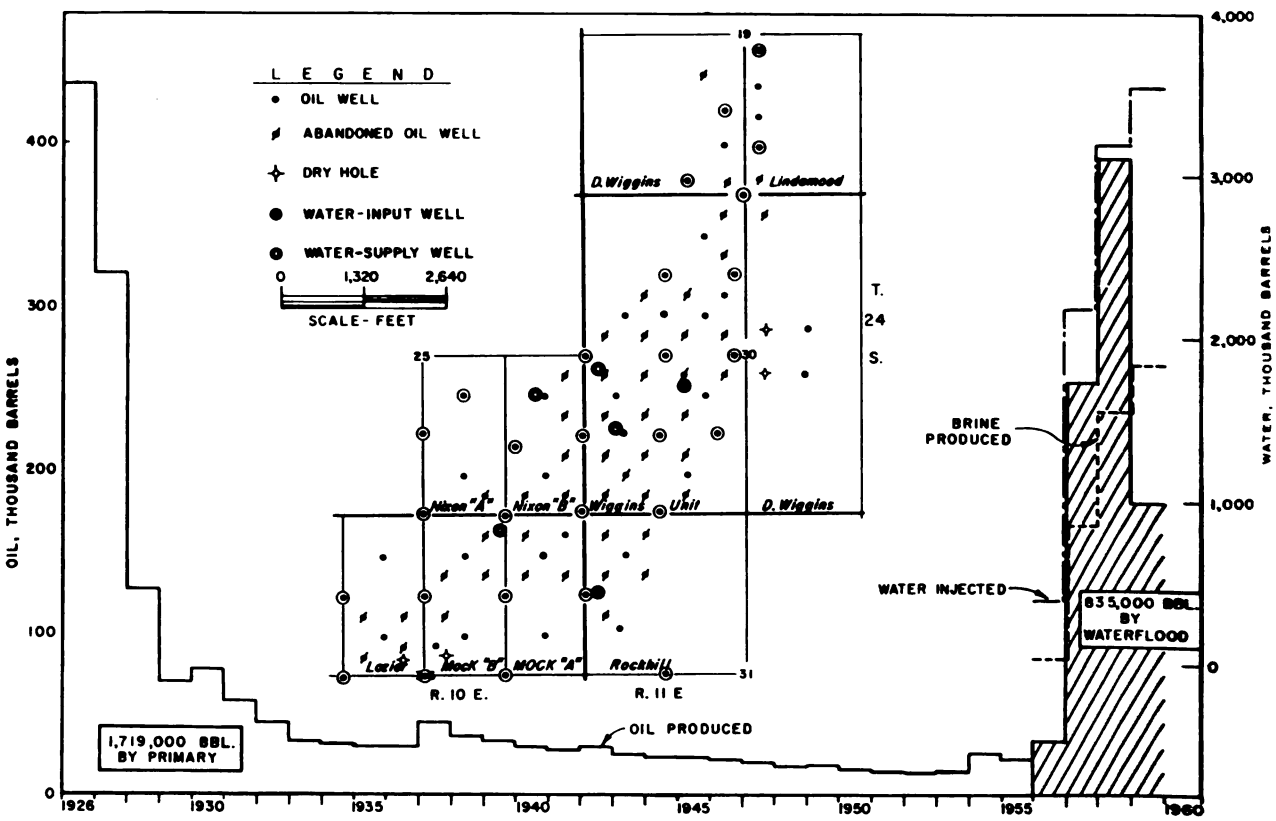

FIGURE 12. - Map and History of Production of Wood Oil Co. Wiggins Project, Greenwood County, Kans., Jan. 1, 1960.

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shows a radioactivity log and results of analysis of a representative core sample taken in October 1956.

History Before Flooding

The discovery well of the Wiggins field was completed in December 1925. The field was developed rapidly, with 43 wells completed in 1926; by 1935 most of the productive area had been drilled. Oil production from the leases included in the flood reached a peak annual rate of approximately 437,000 barrels in 1926 (fig. 12). During the next few years, the rate of production decline was rapid, typical for solution-gas drive reservoirs produced by unrestricted methods. From an annual rate of production of about 33,000 barrels of oil in 1933, the rate of decline was gradual to approximately 22,000 barrels in 1955, except for a few peaks resulting from additional development. An estimated 1,712,000 barrels of oil or 2,460 barrels per acre was recovered by primary methods from the 696 productive acres before waterflooding began.

Method of Completing and Operating Wells

The original primary wells were drilled by cable tools. Most of them were completed with 40 to 50 feet of 12½-inch surface casing, 500 to 600 feet

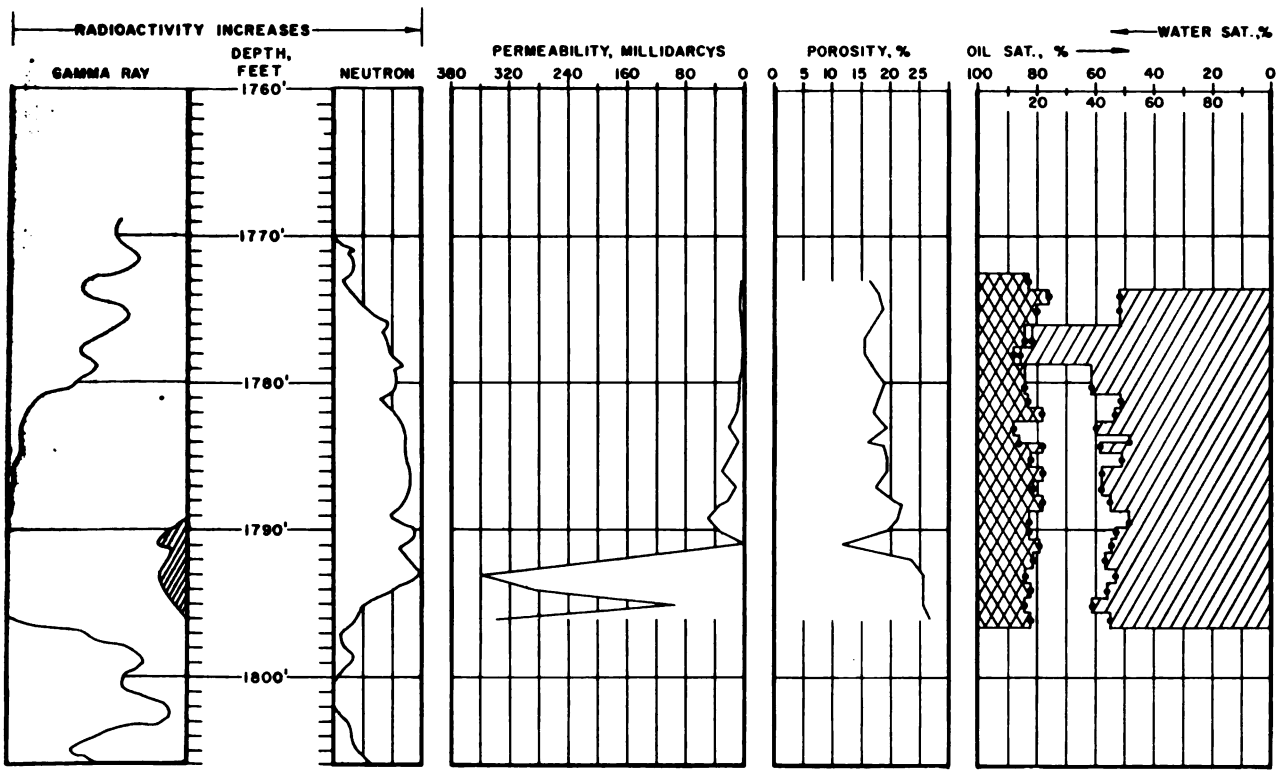

FIGURE 13. - Representative Radioactivity Log and Core Analysis of Cattleman and Wood Oil Co. Wiggins Project, Greenwood County, Kans.

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of 10-inch casing, 1,000 to 1,100 feet of 8-5/8-inch casing, and 1,800 feet of 6-5/8 casing. The casing strings were not cemented. The sand was shot with 100 quarts of nitrogycerin. The wells were pumped by central power units.

The Wiggins waterflood was developed by drilling input wells on a spacing pattern of 40-acres per well, at the corners of 40-acre tracts. New oil wells were drilled in the center of the 40-acre tracts. Old producing wells were not abandoned until their production reached a high water-oil ratio.

Input wells were drilled with rotary tools to the base of the Cattleman sand, where 4½-inch casing was set on bottom and was cemented with 100 to 150 sacks of cement. The casing was perforated opposite the sand section with four shots per foot. Three of the water-input wells were acidized with 750 gallons of acid, and three others were fractured with 5,000 pounds of sand and water. Later, the size of the fracture treatment was increased to 10,000 pounds of sand, and two of the wells originally fractured with 5,000 pounds were refractured.

New oil wells were completed similar to input wells with either 4½- or 5½-inch casing set and cemented through the sand and perforated with 4 shots per foot. Ten of the oil wells were fractured originally with 5,000 pounds of sand and water, and two later were refractured with 10,000 pounds of sand and water. Two wells (one a refractured well) were fractured with 20,000 pounds of sand. The oil wells were pumped by individual units powered by electric motors.

Source and Treatment of Water

Brine for flooding is obtained from six supply wells completed in the Douglas sand formation at a total average depth of 955 feet. The wells are equipped with Reda submergible pumps.

The simplicity of the water-treating plant (fig. 14) is the outstanding feature of this project. Water from the Douglas supply wells is pumped through a closed system into a battery of four 500-barrel tanks, where it is mixed with produced water from five tank batteries. An oil seal on top of the water minimizes exposure of the water to the atmosphere. The mixed water flows by gravity from the 500-barrel tanks into the suction sides of the injection pumps. The operation of the water-supply wells is controlled by float-level controls on two of the 500-barrel tanks. The volume of water injected into 14 input wells is regulated and metered through a central manifold at the pressure plant. Four-inch lines that extend to the north and south, from the central manifold, furnish water to two smaller manifolds that service wells in the north and south extremities of the flood.

The produced brine is collected at the tank batteries in 200-barrel tanks, with an oil seal on top of the water to minimize exposure of the brine to the atmosphere. The brine is treated daily at the tank batteries with 2 quarts of Ecco C-910 for each 1,000 barrels of water for corrosion control. Magnesium anodes are used in nine water-storage tanks and seven gunbarrels for cathodic protection.

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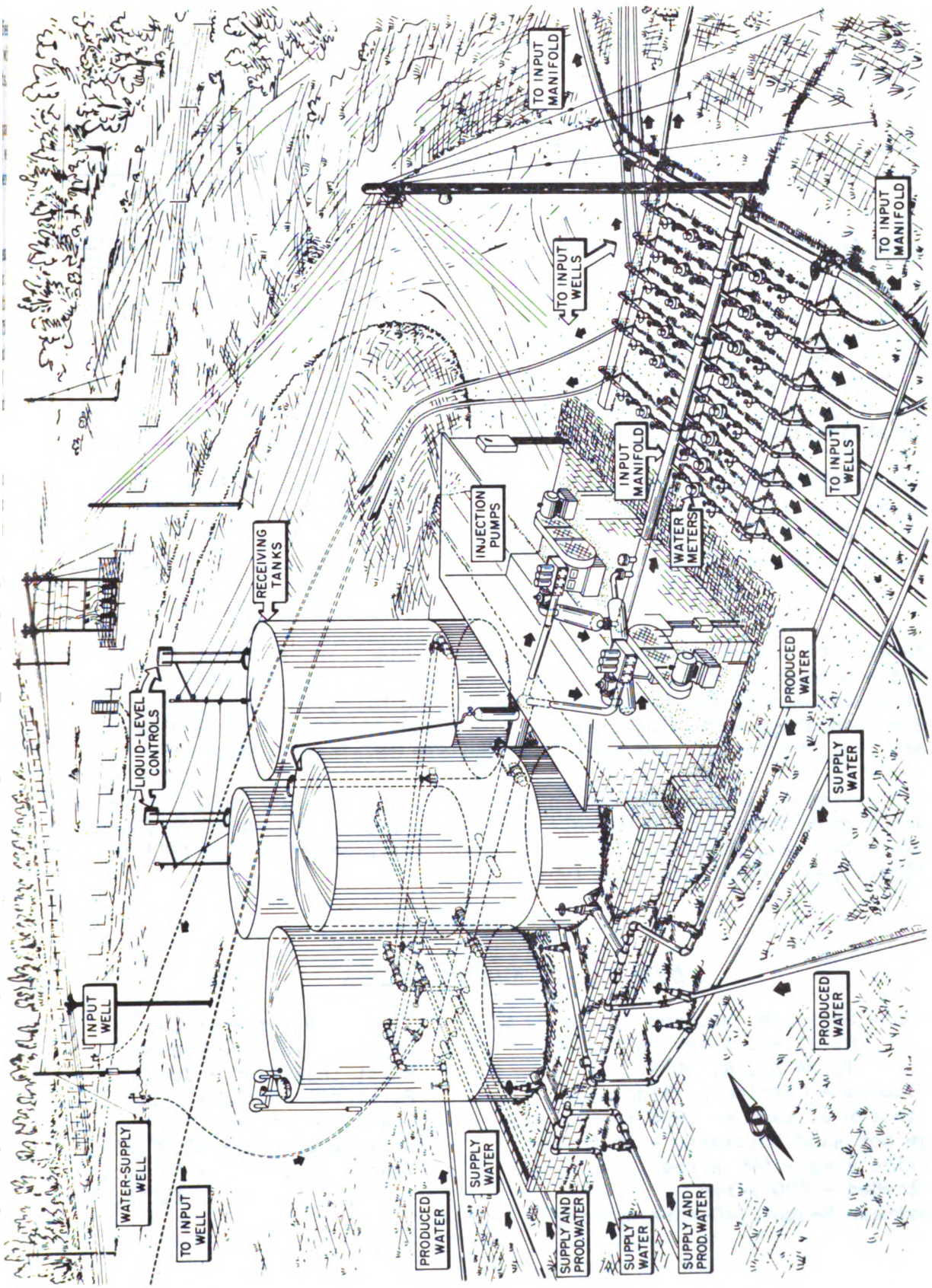

FIGURE 14. - Water-Treating Plant of Wood Oil Co. Wiggins Project, Greenwood County, Kans.

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Mineral analyses of the injection waters are shown in table 4.

Table 4. - Mineral analyses of injection waters, Wood Oil Co., Wiggins project, Greenwood County, Kans.

	Douglas Sand Water		Produced brine	
Ion or radical	Milligrams per liter	Reacting values, Percent Palmer	Milligrams per liter	Reacting value, percent Palmer
Calcium (Ca).....	4,200	6.17	4,300	6.35
Magnesium (Mg).....	800	1.93	870	2.12
Sodium (Na).....	32,800	41.90	32,900	41.53
Carbonate (CO_3).....	0	0	0	0
Bicarbonate (HCO_3).....	62	.03	55	.03
Sulfate (SO_4).....	446	.27	404	.25
Chloride (Cl).....	59,900	49.70	59,600	49.72
Total solids.....	98,208	100.00	98,129	100.00
Hydrogen Sulfide (H_2S)...	- -		Present	
Barium (Ba).....	61		198	
Specific gravity.....	1.069		1.070	
pH.....	7.58		7.10	

Results of Flooding

Results of waterflooding on the Wiggins project are shown in figure 12 and in the Summary of Operations. To December 31, 1959, approximately 842,000 barrels of oil was gained by injecting 9,305,000 barrels of water. This equals a cumulative water-injected to oil-produced ratio of 11 to 1 and a recovery of 1,256 barrels per acre from the 670 developed acres.

The response to water injection was rapid, and a peak annual rate of production of more than 390,000 barrels of oil was reached in 1958, $2\frac{1}{2}$ years after injection was started. From this peak, the production declined to approximately 179,000 barrels in 1959.

Summary of Operations

Wood Oil Co. Wiggins project

Location - Secs. 19, 30, and 31, T. 24 S., R. 11 E., Secs. 25 and 36, T. 24 S., R. 10 E.
Sand flooded - Cattleman (Wiggins)
Depth to top of sand - 1,800 feet
Average net sand thickness - 15.6 feet
Productive area - 696 acres
Area flooded - 670 acres
Well pattern 5-spot (40-acre spacing)
Type of water - brine
Type of system - closed
First injection - June 1956
First oil increase - Sept. 1956
Status - active
Gravity of oil - 40.9° API
Viscosity of oil - 38 sec. at 100°F.

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Oil produced by years, barrels

Year	Oil produced	Year	Oil produced	Year	Oil produced	Year	Oil produced
1926....	436,581	1935....	29,627	1944....	24,167	1953....	15,326
1927....	320,446	1936....	29,694	1945....	23,677	1954....	25,127
1928....	126,347	1937....	44,987	1946....	21,650	1955....	22,130
1929....	69,277	1938....	36,851	1947....	19,850	1956....	31,441
1930....	77,583	1939....	32,845	1948....	18,092	1957....	234,042
1931....	57,867	1940....	29,842	1949....	18,276	1958....	390,773
1932....	44,636	1941....	28,029	1950....	15,928	1959....	178,665
1933....	33,116	1942....	30,341	1951....	14,971	.....	.....
1934....	31,844	1943....	25,390	1952....	14,323	.....	.....

Summary of waterflood performance

Years	Acres flooded	Active input wells	Active oil wells	Cumulative oil recovery bbl. per acre	Cumulative water-injected: Oil-produced ratio
Dec. 31, 1956.....	160	13	26	121	21
Dec. 31, 1957.....	547	22	46	497	9
Dec. 31, 1958.....	670	26	35	989	9
Dec. 31, 1959.....	670	28	27	1,256	11

Data to Jan. 1, 1960

	Barrels
Primary oil recovered, estimated	1,712,204
Primary oil recovered per acre (696 acres)	2,460
Oil recovered by waterflooding	841,537
Oil recovered per acre by waterflooding (670 acres)	1,256
Total oil recovered	2,553,741
Total oil recovered per acre (696 acres)	3,669
Total water injected	9,305,073
Water produced beginning June 1, 1956	4,271,508

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Monthly record of water injected and oil and water produced, barrels

	1956			1957		
	Water injected	Oil produced	Water produced	Water injected	Oil produced	Water produced
January.....	- -	- -	- -	153,352	6,241	17,577
February.....	- -	- -	- -	143,480	9,379	23,072
March.....	- -	- -	- -	155,271	13,388	28,799
April.....	- -	- -	- -	153,562	19,985	43,650
May.....	- -	- -	- -	155,460	32,298	87,885
June.....	12,873	- -	3,300	148,569	29,267	81,810
July.....	44,515	- -	3,410	154,768	27,532	91,109
August.....	46,171	- -	3,410	156,217	25,051	104,315
September.....	46,956	2,364	3,300	216,797	24,844	94,920
October.....	46,554	4,437	3,410	268,846	20,627	101,339
November.....	45,922	5,977	2,910	221,933	20,382	78,690
December.....	154,977	6,521	17,887	250,622	23,806	94,984
Total.....	397,968	19,299	37,627	2,178,877	252,800	848,150

	1958			1959		
January.....	257,426	26,136	106,826	298,644	22,714	145,948
February.....	236,655	25,426	93,757	274,477	17,724	144,844
March.....	251,410	31,969	115,351	293,534	17,941	127,999
April.....	247,001	37,068	123,180	287,330	15,609	138,540
May.....	246,680	37,782	112,437	314,355	16,035	151,621
June.....	256,205	36,985	119,220	286,750	14,446	143,700
July.....	258,731	36,966	130,944	286,388	13,895	169,601
August.....	287,377	34,509	140,895	310,565	13,697	166,315
September.....	284,573	30,326	151,950	282,414	11,718	164,520
October.....	284,919	36,360	157,821	304,972	12,533	149,110
November.....	279,385	30,723	151,500	297,107	10,901	158,430
December.....	294,425	26,523	149,141	306,905	11,452	172,081
Total.....	3,184,787	390,773	1,553,022	3,543,441	178,665	1,832,709

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